An analysis of factors influencing the growth of photovoltaics in Germany, and the outlook to 2020

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An analysis of factors influencing the growth of photovoltaics in Germany, and the outlook to 2020

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ABSTRACT

The research investigated drivers of adoption of solar photovoltaic (PV) systems in Germany, questioning the recurrent simple linkage of PV growth with "generous subsidies". It tested the hypothesis that feed-in tariffs are an enabler, not merely a financial impetus, promoting installation of PV not by making it lucratively *profitable*, but *financeable* for people who want it for other reasons. The primary focus was on household PV systems. Potential drivers of PV adoption examined include environment consciousness, desire for independence from large utilities, and social influence. Literature review encompasses PV support-demand linkage, policy, attitudes to PV, and relevance of e.g. innovation diffusion theory and intertemporal decision-making. The hypothesis was tested by conducting a recent online survey in Germany (400 responses); and comparison of PV capacity installed against expected return on investment (RoI), modelled using an original dataset based on over 1200 "Solar League" towns. Several findings support the hypothesis. Survey respondents rated financeability significantly more important than profitability as reason for wanting PV; climate concern also rated highly. Having children correlates with desire for PV. Much PV capacity has been installed where expected RoI is comparable to risk-free savings account rates; recent household systems growth has not tracked higher RoI. The policy outlook regarding PV support is uncertain: the new government since 2009 has cut feed-in tariffs sharply, and plans extended nuclear plant operating lifetimes. Potential electoral cost may restrain further measures. Capacity growth in Germany continued, 7400MWp (forecast) in 2010, and much potential remains including for household systems. Industry efforts, technological developments, and increasing production scale as new markets

emerge (e.g. USA, China, Italy) continue to push down costs. Some thoughts are offered on what achievement of "grid parity" may mean. The outlook in Germany is for substantial steady annual PV growth of 3-5GWp. Globally, PV seems now unstoppable.

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In Germany

Michael Ziegler at www.photovoltaikumfrage.de generously agreed to host the fieldwork survey on his website at no charge, then later validated and collated the responses. Several friends reviewed the draft survey and suggested amendments to the German wording: Dr-Ing. Rainer Eckart, Rita Eckart, Dr. Myrthe Eckart. Assistance with initial efforts to distribute printed questionnaires came from Dr Christian Kaßner in Hattingen, Iris Wunder MA (Open) and mayor Andreas Schwarz in Strullendorf, and not least mayor Stefan Raetz in Rheinbach and the Freunde von Sevenoaks led by Siegfried and Birgit Formanski. SolarWatt AG in Dresden sponsored the author's attendance at the 21st European Photovoltaic Solar Energy Conference in Dresden, 2006.

In the UK

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Last but most certainly not least, the author's wife Keiko showed great support, and forbearance as the research delayed all those household tasks which demand attention.

Publications arising from the research

Plater, S., Boyle, G., 2006. "Germany: is PV going where the sunshine and money are?". Proceedings of the 21st European Photovoltaic Solar Energy Conference, Dresden 2006.

Plater, S., Boyle, G., 2009. "Germany: is the PV capacity following the money?". Proceedings of the 24th European Photovoltaic Solar Energy Conference, Hamburg 2009.

Plater, S., 2009. "An initial analysis of options for a UK feed-in tariff for photovoltaic energy, from an array owner's viewpoint." Environmental Research Letters 4, 044004

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Chapter 1 : INTRODUCTION - ISSUES RESEARCHED

".... I would argue that Photovoltaics is ultimately the most promising of all energy technologies giving us the best option to overcome global energy crises. .... It bears by far the largest potential – larger than that of all other renewable energy sources."

Dr Hermann Scheer, in Foreword to Mendonça 2009, p. xi

1.1 Recent growth of PV in Germany

Germany's performance in building up renewable energy capacity has been impressive, in many respects world-leading, not least in solar photovoltaics (PV). Total installed PV capacity at the end of 2009 was 9.8 GWpeak, 62.5% of total European capacity of 15.7 GWp and 42.8% of total world capacity; annual growth in Germany in 2009 was 3.8 GWp, 67% of that in the EU and 53% of global growth (EPIA & Greenpeace, 2011). Figure 1 illustrates the rapid rate of annual capacity build-up since 2000 and its acceleration from 2004 onwards.

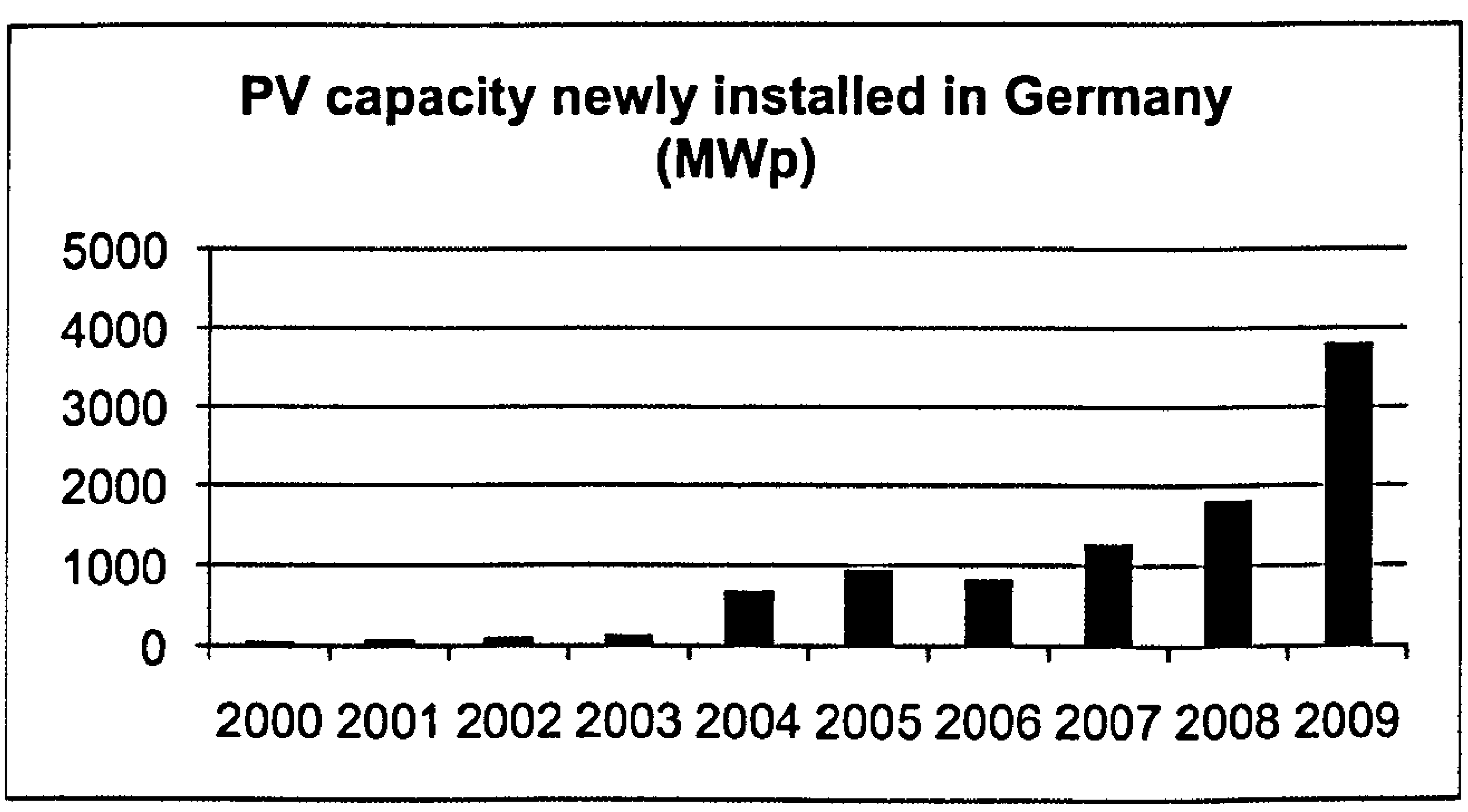


Figure 1 : annual growth of installed PV capacity in Germany in MWp, 2000–2009 (data source EPIA & Greenpeace, 2011)

The research presented in this thesis examines whether the build-up of PV capacity in Germany is likely to continue over the next 5-10 years, meaning in the period approaching 2020, at a rate similar to that between 2004-2009. Accordingly it considers the following issues.

- What have been the drivers of PV build-up in Germany up to now?

- Are sociology and consumer psychology relevant?
- Will the drivers of PV growth continue to apply?
- Which other factors bear on the outlook for PV in Germany?

The German PV market comprises several segments: small systems on domestic roofs; medium sized systems on public, commercial and agricultural buildings; and large, often megawatt scale, ground-based systems. Market segmentation is discussed more fully in section 6.3.4 on pages 222-238.

Within its overall consideration of the outlook for growth of PV capacity in Germany, the research examined in greater depth the domestic segment, with particular reference to what motivates individuals to have PV installed on their roof, and to the role of the feed-in tariff incentive - 'bribe' or enabler? Section 1.3 below describes how the German feed-in tariff operates.

Figure 2 shows the breakdown of installed PV capacity in Germany by type of array, as at the end of 2009. The domestic segment of the market, i.e. smaller rooftop systems on owned and rented dwellings, comprised just under 37% of total capacity.

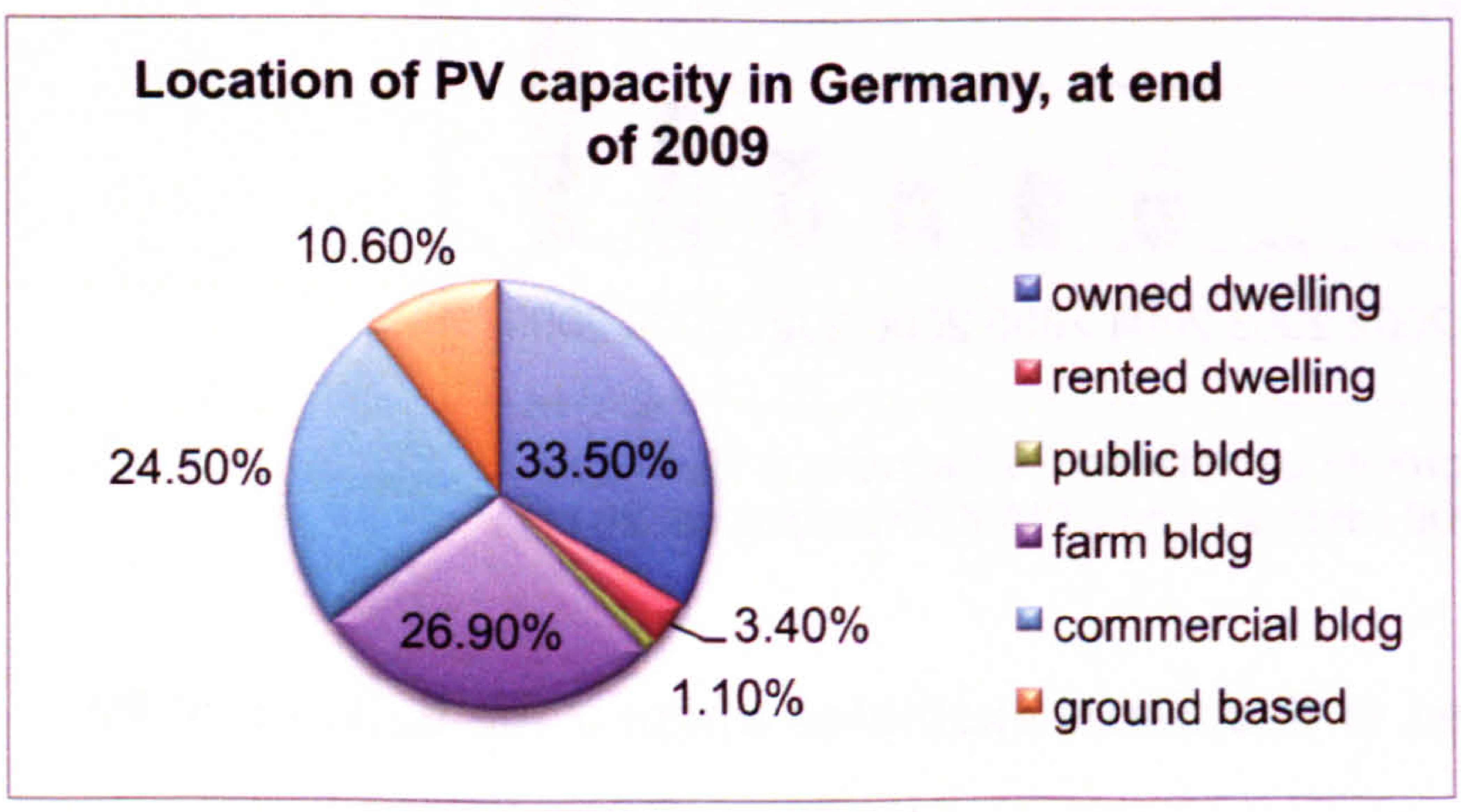


Figure 2 : PV capacity in Germany by type of building on which installed, or whether in ground based arrays (source: federal grid agency)

1.2 Reasons for growth of PV in Germany

The following are pertinent issues to address in seeking to understand why the build-up of PV in Germany so far has taken place.

a. the policy framework - how the German government has promoted PV, among other renewables, and for what reasons.

b. the degree of linkage between PV support schemes and build-up rate.

c. which, if any, other drivers of demand for PV are operating - including socio-psychological factors.

The literature review in Chapter 3 will explore those issues, including the "feed-in tariff" (FiT) premium payment for electricity generated by renewable energy installations and exported to the grid, and why it was preferred to quota based systems; and socio-psychological factors including environment consciousness, consumer psychology and innovation diffusion theory.

1.3 The German feed-in tariff

The German 'feed-in tariff' system of incentives to generate electricity from renewable energy was established by the Renewable Energy Sources Law (German acronym EEG) of 2000, and updated with improved terms by the EEG 2004. Details in the following description are those which apply to electricity from PV systems. Feed-in tariff rates for all renewables are published by the federal environment ministry; for example those set by the 2009 revision of the EEG are downloadable from http://www.erneuerbare-energien.de/inhalt/42033/ .

1.3.1 Feed-in tariff rate

The feed-in tariff (FiT) is paid at a fixed rate per kWh generated. That is an incentive to install more efficient systems to maximise electricity output and hence FiT income. The rate depends upon the peak rated capacity of the PV system, in four bands for roof-mounted systems - up to 30kWp, 30-100 kWp, 100-1000 kWp, over 1000 kWp - plus one for ground-mounted systems of any size. A given PV system will receive the same FiT rate which applies in the calendar year of its installation, for the remaining months of that year plus the 20 following years. That applies even if the system owner moves house, and takes the system to install on the new residence. If tax (VAT in the UK) is paid on the PV system, then FiT income is tax-free. Conversely, the system may be installed free of tax, which is then payable on FiT income. Which is the better option depends on individual circumstances.

The EEG stipulates an annual reduction ('degression') in the FiT rate, intended to keep it in line with falling PV system costs, and to encourage the industry to achieve such cost reductions on a continuing basis. In 2010 the government imposed a further in-year FiT rate reduction, with the possibility of another in mid-2011. However, there has never been a retrospective cut in FiT rates.

Figure 3 overleaf shows the evolution of the average price of a <10kWp PV system and of the FiT rate for small systems, from 2000-2010* (upper chart); and a simple index (lower chart) of 'system price' ÷ 'FiT rate' (disregarding units), which shows that the FiT rate has by and large remained aligned with falling system price since 2003. Before then the FiT rate was somewhat low, relative to system price. From 2003-2010* this index has varied in the fairly narrow range 89-119. [* For clarity of presentation, the 2010 figure for FiT rate is for the first half of the year; it was cut by 13% from July and a further 3% from October, increasing the index to 105 then 108, still well within the 2003-2010 range.]

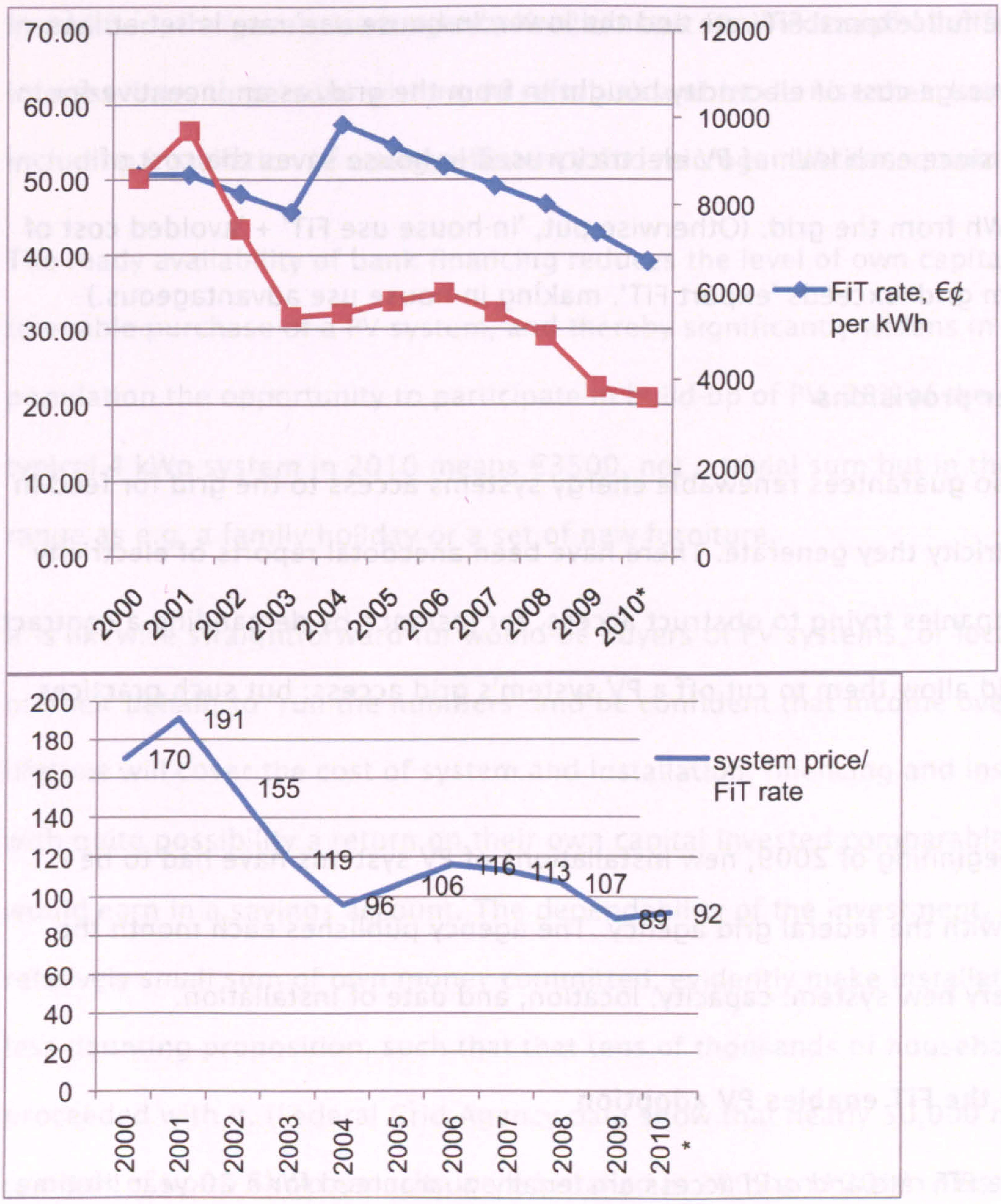


Figure 3: upper chart – FiT rate in €¢ per kWh and average price per kWp installed of small (<10kWp) PV systems, 2000–2010 first half; lower chart – index of system price as multiple of FiT rate, disregarding units. Sources: EuPD Research, Bonn (system price); Federal Grid Agency (FiT rate).

1.3.2 Export vs in-house use

Up to 2008 all the electricity generated by a PV system was exported to the grid and received FiT payment; all electricity used by e.g. a household was bought in from the grid. From 2009, however, PV system owners were given the option of using some of the electricity it generated in-house, while still receiving FiT payment for that electricity, but at a lower rate than for electricity exported to the grid. This applies only to systems of up to 30 kWp capacity. The differential between the full 'export' FiT rate and the lower 'in-house use' rate is set at less than the average cost of electricity bought in from the grid, as an incentive for in-house use, since each kWh of PV electricity used in-house saves the cost of buying a kWh from the grid. (Otherwise put, 'in-house use FiT' + 'avoided cost of buying from grid' exceeds 'export FiT', making in-house use advantageous.)

1.3.3 Other provisions

The EEG also guarantees renewable energy systems access to the grid for feed-in of the electricity they generate. There have been anecdotal reports of electricity supply companies trying to obstruct access, for instance by demanding a contract which would allow them to cut off a PV system's grid access; but such practices are illegal.

Since the beginning of 2009, new installations of PV systems have had to be registered with the federal grid agency. The agency publishes each month the data on every new system: capacity, location, and date of installation.

1.3.4 How the FiT enables PV adoption

Because the FiT rate and grid access are legally guaranteed for a 20 year lifetime, and the government has never imposed retrospective cuts, the income stream from FiT payments is reliable and "bankable". That is, banks in Germany assess investment in a PV system as very low risk, and are willing to lend a substantial proportion of the cost, typically 75% (cf 5.2.3, p.169-171 below). Availability of finance was reportedly unaffacted by the "credit crunch" of 2008-09 : see 6.4.4.1, p.230 below and Pohl (2009).

Germany still has an extensive network of local retail banks, known as 'Sparkasse' at town (Stadt-) and district (Kreis-) level, along with Land and national banks, and specialised institutions such as Umweltbank ("Environment Bank") in Nürnberg.

In addition, the government agency Kreditanstalt für Wiederaufbau offers low interest loans to persons wishing to refurbish and modernise their homes, including installation of energy efficiency and microgeneration equipment.

The ready availability of bank financing reduces the level of own capital required to enable purchase of a PV system, and thereby significantly widens in the population the opportunity to participate in build-up of PV. 25% of the cost of a typical 4 kWp system in 2010 means €3500, not a trivial sum but in the same range as e.g. a family holiday or a set of new furniture.

It is likewise straightforward for would-be buyers of PV systems, or local advisors on their behalf, to "run the numbers" and be confident that income over the FiT's lifetime will cover the cost of system and installation, financing and insurance, with quite possibility a return on their own capital invested comparable to what it would earn in a savings account. The dependability of the investment, and the relatively small sum of own money committed, evidently make installation of PV a less daunting proposition, such that that tens of thousands of households have proceeded with it. (Federal Grid Agency data show that nearly 50,000 new systems of up to 5kWp capacity were installed in 2009 and 2010; plus almost 130,000 of 5-10kWp.)

1.3.5 Alternatives to installation of PV

A household in Germany with, say, €3500 available has several other low risk investment options. The most obvious are "high street" savings accounts, which offer around 3% interest or a little more in a fixed term bond. Professional managed "Solar Funds", akin to unit trusts or mutual funds, enable investment in a slice of a large PV system; they promise returns of around 6%. Similar but paying somewhat less interest (about 4%) is a 'Bürgerbeteiligung' ("citizen participation"), in which residents can buy a piece of a PV system on a communal building. A further possibility is to rent out roof space to a company, which then installs a PV system and takes the FiT income; the rent paid is typically much less than the household could earn by installing its own system, but of course no capital investment is required.

1.4 Is it simply about profit?

The rapid growth of PV capacity in Germany since the introduction of the present FiT, with improved rates, in 2004 clearly suggests that the FiT has acted as catalyst of installation of PV. Less clear is *how* it has done so.

Widespread in the literature is the implication that there is a strong and direct linkage of cause and effect, between financial incentives for PV and the build-up of capacity. That implication is frequently formulated in quite plain statements that the market for PV in Germany depends entirely, or almost entirely, on "subsidies", often described moreover as "generous". Anticipating the literature review in order to illustrate this, a particularly stark example is the assertion by Paula Mints of Navigant Consulting that ".... demand for photovoltaic products exists because of subsidies, and would not exist without them." (Mints, 2006). Her view had not changed by November 2008: "The market for PV products continues to be driven by incentives - THERE IS NO TRUE DEMAND PULL AND A NATURAL MARKET DOES NOT CURRENTLY EXIST" (Mints, 2008).

This general perception that "subsidies" (an inexact term to describe Germany's market build-up support mechanism) in a simple and direct way <u>create</u> demand for PV seems unsatisfactory and too broad brush. Papers relating increases in government support to subsequent increases in capacity installed tend to present the position only at macro level and to be somewhat lacking in analysis. They simply assume a causative linkage between support and demand, without investigating its nature and considering other possible reasons for growth in PV capacity besides financial gain. It may be a matter of oversight: observing an apparently straightforward relationship of cause (incentives) to effect (demand), and therefore not perceiving any need for further enquiry to test the validity of that observation.

The research presented in this thesis seeks to contribute to filling this gap in the literature, by getting below the surface of the - it is believed misleadingly - simple linkage between support and demand. That necessitates examination of the extent to which demand for PV in Germany results from incentives. Do the incentives *create* demand which would otherwise not exist? Or do they *unleash* latent demand by making it possible to actualise it?

1.5 Financial aspects

This is not to imply that financial considerations, such as payback time or potential returns from alternative uses of the money, carry no weight. The decision to buy a PV array is not one-dimensional or black and white. Few people are so affluent that they can buy a PV array without considering its cost. In deciding whether to buy, the relative weight of the factors that people take into account will naturally vary from one category of person to another, and between individuals. In testing the hypothesis, it is clearly desirable to investigate the extent to which the following money-related factors matter.

- The "headline" cost, for a typical 4 kWpeak (kWp) PV system is still above €10,000 even after recent price falls. Is that substantial enough to deter individuals from installing?
- Financing of the cost: are people willing to take on substantial borrowing, or is reluctance to do so an obstacle?

- Return on investment – is one required, and if so how must it compare with, for instance, interest levels available in savings accounts? Does the incentive system have to "bribe" people to buy PV, or just encourage them?

- Payback time – what is an acceptable timeframe, given the 20 year life of income from the feed-in tariff?

It is postulated that groups and individuals are located at various points in a 'buy-not buy space', with coordinates of extent of *desire push* to have PV and of *incentive pull* to have it. The resultant of the 'desire push' component, made up of one or more drivers, and of the 'incentive pull' component (incorporating financial considerations, including any expectation regarding return on investment) determines whether a given person crosses the threshold to a decision to buy a PV array. This can be represented graphically as in Figure 4 below.

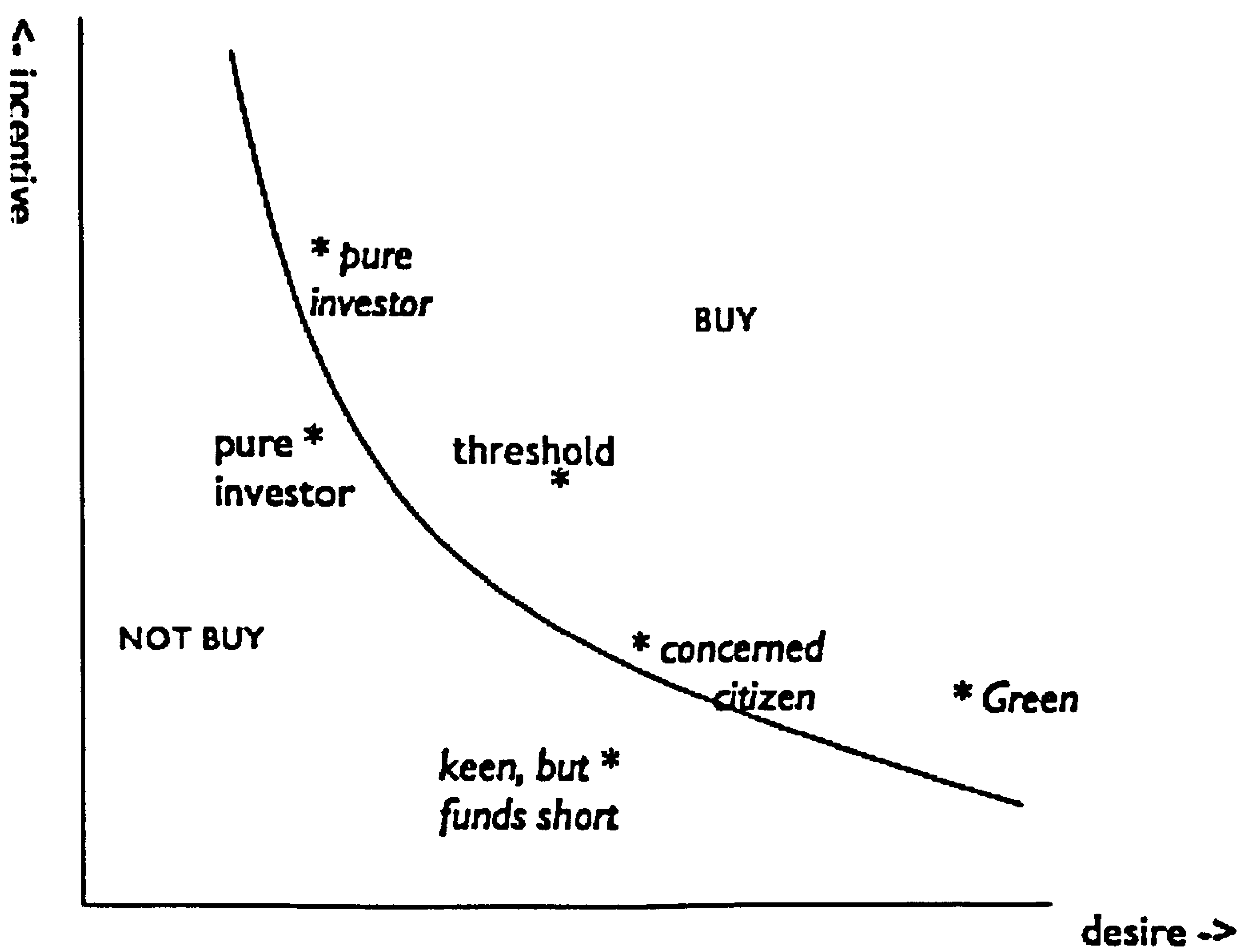


Figure 4 : conceptual representation of 'buy/not buy space'

If someone's desire for PV is stronger, less incentive is needed to draw them into 'buy' territory. Conversely, less desire means more incentive required to cross the threshold to 'buy'. One could combine different factors in 'desire' as adding up to an overall score on the X-axis ; the Y-axis score would have components of incentive level and expectation as to return on investment. To plot a precise threshold between 'buy' and 'not buy' would involve analysis of where a large number of cases plot in the space, since individuals will display varied combinations of desire for PV and wish for incentives.

The principal financial elements of the 'incentive pull' component are as identified above. It is of course essential similarly to examine the elements of the 'desire push' component, meaning the *non*-financial drivers of desire to have a PV array. The following are the main categories to consider. The list does not claim to be exhaustive, and it would be possible to group the same drivers in several different ways.

a) Beliefs: e.g. environment consciousness, "Green" ideology.

b) Good citizenship: e.g. concern about climate change, desire to contribute to combatting it.

c) Social: e.g. being inspired by a local champion or campaign, simple desire to "keep up with the Müllers".

d) Individual psychology: e.g. desire for independence from electricity companies, keenness on new technology.

e) Patriotism: e.g. wish to support German industry and employment.

As noted above, existing socio-psychological theory should be examined for the extent of its applicability to adoption of PV systems. Potentially relevant aspects are consumer psychology, especially in relation to "environmental" products and to high cost items, and innovation diffusion theory.

Investigation of all these factors has both a "hitherto" and a "henceforth" dimension. The former is necessary for an understanding of the basis of the rapid build-up of PV capacity in Germany so far. Since this research addresses the question of future PV capacity growth in Germany, it is likewise necessary to examine to what extent each factor may continue to apply. Of particular importance is the policy framework, not least the significant shift in the political landscape following the German federal elections in September 2009 and change of government.

1.6 Obstacles to increased take-up of PV

In assessing the 'desire push' and 'incentive pull' components of the postulated 'buy-not buy space' (Figure 4 on page 10 above), possible obstacles to actualisation of demand for PV must be taken into account. In the German system, feed-in tariff support has up to now not been capped. That means that there is no limit on installed PV capacity, either in a given year or cumulatively, above which new PV installations no longer qualify for the FiT. In that case, and if the incentives are really so "generous", why is installed PV capacity in Germany not even greater? One possible answer is of course that the incentives are not in fact so "generous". Another, and related, possible answer is that they do not need to be, in order to promote installation of new PV capacity: the hypothesis that this research tests. It would, however, be remiss not to take account of other potential obstacles, such as the following.

- Limited availability of financing, especially given the "credit crunch".
- Lack of knowledge, information, understanding.
- Reluctance to undertake a large investment - possibly coupled with lack of understanding of its low-risk nature and of financing options.

- Supply shortage, of PV modules or of qualified installers.
- Resistance from landlord or fellow tenants.
- Physical factors e.g. insufficient south-facing roof area, or shading.
- Waiting for PV array prices to fall further.

1.7 Other factors bearing on the outlook for PV

Assessment of the outlook for the rate of growth of PV capacity in Germany must naturally take into account "context" factors which may bear on those indicated above, and thereby affect either the 'incentive pull' or the 'desire push' component. The impacts of such factors may well be interrelated.

One factor already alluded to is politics. The feed-in tariff system of support for renewable energy in Germany had majority support since the late 1990s, when the SPD-Green coalition government pushed through the first Renewable Energy Sources Act (Erneuerbare Energie Gesetz, EEG) of 2000. Support continued through the Grand Coalition of the centre-left Social Democrat Party (SDP) and the centre-right Christian Democratic Union with its Bavarian sister party the Christian Social Union (CDU/CSU), formed after the inconclusive federal election in 2005. The tension between the halves of the coalition was by then rather about the law requiring phase-out of nuclear power. However, near the end of the 2008 review of the EEG, the CDU/CSU attempted to force a 30% reduction in feed-in tariff (FiT) rates for PV. The reasons for that and the subsequent measures to cut the PV FiT need examination. So does the level of influence of the Free Democratic Party (FDP), now coalition partner with CDU/CSU in a right-leaning and "business friendly" government. The FDP called for a shift from feed-in tariffs to a certificate trading system for new renewable energy installations (SFV, 2009a).

Intuitively it seems unlikely that personal and social motivations would change significantly in the space of just a few years. Increasing concern about the threat and impacts of climate change, and the prospect of rising fossil fuel costs as supply falls behind increasing demand, ought if anything to strengthen society's desire to build up PV and other renewable energy capacity. On the other hand, economic pressures could affect the financial component of decisions about buying PV, and thus shift the threshold of a 'buy' decision, postulated above. The level of actual PV capacity installation by individual householders, and by other groups, will of course provide a concrete measure. It will be interesting to see whether the trend of increase in capacity conforms to the predictions of innovation diffusion theory, such as the "innovators-early adopters-early majority" section of Everett Rogers' S-curve (Rogers, 2003): see Chapter 3 section 7.6. Monitoring of opinion polls on environmental consciousness and approval of renewable energy - which have to date been very positive, especially about solar energy - should also be illuminating.

1.8 PV cost and support level

The central hypothesis that this thesis tests is that, at least for individual householders, *financeability* rather than *profitability* is the necessary condition for a decision to buy a PV array. Whether the hypothesis is supported or not, however, the cost of PV will be an important factor in the outlook for PV capacity growth. One should not, however, anticipate a simple linear relationship between cost reduction and capacity increase, because of the interplay between the cost of PV and the level of incentive needed to promote capacity growth. This is illustrated by the 2008 revision to the terms of the German feed-in tariff. Until then, the level of FiT for electricity from a newly installed PV array (payable then at the same rate for 20 years) reduced by 5% each year, in line with the same "experience curve" 5% annual reduction in array costs which had obtained for at least a decade (EPIA & PVTP, 2010). The purpose of this 'taper' is to maintain pressure on PV manufacturers to drive down costs. The 2008 review increased the taper rate to 8%, and further to 9% from 2011, in effect challenging the industry to achieve greater cost reductions. Demand for PV grew markedly in 2009, helped by a sharp fall in system prices resulting from collapse of the Spanish market. Political developments led to further cuts in feed-in tariff levels in the course of 2010, and other changes to the system: see Chapter 6.1 .

Which developments could affect PV cost? The principal areas to consider are PV market growth hence production scale, and technological advances.

Since 2005 Germany has been the principal motor of PV capacity growth, by 2009 accounting for 53% of the global market. Other markets have, however, increased in importance, in particular those which adopted the feed-in tariff incentive system. Assessment of the outlook for PV cost must include the evolution of the market for PV globally, and what effect it has had so far and may be expected to have in the next 5-10 years, through economies of scale from the scaling up of production facilities in both established and newer technologies. In addition, PV manufacturers have achieved and continue to achieve incremental improvements in cell technology and in production processes, as they strive to keep the price of PV arrays falling in line with the taper of the feed-in tariff rate. These deliver, for instance, increases in conversion efficiency of sunlight into electricity, and reductions in the amount of silicon needed to make a cell. Relevant questions are which further such improvements are in the pipeline, to what extent might they impact upon PV cost, and possible constraints such as finance for investment and supply of key materials. These factors are addressed in Chapter 6.2 and 6.3.

What does this mean to a person considering purchase of a PV array? On the face of it, what matters most is the ability to "run the numbers" for array output and hence feed-in tariff income on the one hand, and for cost of the array (allowing for financing and maintenance) on the other, to calculate whether the array is likely to be financeable - or profitable, if that is what the would-be buyer requires. It is for consideration whether this is the case equally for a would-be buyer looking for an attractive return on the investment (and for what constitutes "attractive"), and for one simply seeking reassurance that the installation will pay for itself without necessarily yielding an appreciable profit.

A wider consideration is that any development which reduces the cost of PV will thereby bring it closer to the point of "grid parity", at which a kWh of electricity generated by a PV array - factoring in the cost of the array and all ancillary costs, including financing - costs the same as the price to a domestic customer of a kWh bought in from the grid. What will be the implications of that for the level of demand for PV, and for the need for and the nature of the system of incentives to install PV ? Chapter 6 section 5 discusses this aspect.

An assessment of the outlook for PV growth in the next 5-10 years must clearly include all of these attitudinal, political and technological factors. Investigating these questions has potential value not only in terms of improved academic understanding. It could also contribute to more effective policy formation by local and national authorities which want to promote the use of solar PV energy. For example, it could help those authorities to judge what level of incentive would be sufficient to realise demand for PV arrays, at less cost e.g. to electricity consumers or ratepayers; and to devise measures to counter obstacles to further growth of PV capacity. Further, better understanding of what drives demand may assist evaluation of the outlook for growth of PV capacity.

1.9 Notes concerning language

Throughout this thesis, German names for geographical entities and acronyms for organisations are used, with translation where necessary for clarity. Expansion of an abbreviation or acronym may be repeated upon subsequent use of it, for ease of reference. Where a readily understood English term exists, it is used: for example, "federal grid agency" for the Bundesnetzagentur (called Federal *Network* Agency on some English language versions of German websites). Some names are abbreviated for simplicity, e.g. BMU as the federal environment ministry, rather than its full name Federal Ministry of the Environment, Nature Conservation and Reactor Safety.

A constituent region of the Federal Republic is referred to as a Land (plural Länder), and by its German name: Table 1 lists the few Länder, the English renderings of whose names are not the same as the German.

Land	**English rendering**
Bayern	Bavaria
Nordrhein-Westfalen	North Rhine-Westphalia
Niedersachsen	Lower Saxony
Mecklenburg-Vorpommern	Mecklenburg-West Pomerania
Rheinland-Pfalz	Rhineland Palatinate
Sachsen	Saxony
Sachsen-Anhalt	Saxony Anhalt

Table 1 : English renderings of certain German Land names

CHAPTER 2 : Research approach

"We should be using Nature's inexhaustible sources of energy – sun, wind and tide. I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that."

(Thomas Alva Edison, 1847-1931)

2.1 How the issues were investigated

The preceding chapter set out the issues and questions that this thesis addresses. This chapter will describe the approach taken to explore those issues and to resolve those questions. That approach comprises several strands, each examining a facet of the question that the thesis title poses: whether the build-up of PV in Germany will continue at a pace similar to that since 2004. In order to address that question, it is essential to understand better what the drivers of the build-up of PV have been and are. The key questions are:

(a) does the prospect of relatively high return on investment constitute the dominant driver of PV installation?

(b) what other drivers operate? what is their interplay with (a)?

(c) to what extent will each of the drivers continue to operate?

To recall, the primary focus of this thesis is on rooftop PV arrays bought by individual households, including those resident in semi-detached and terraced houses, and in apartment buildings. It will also give limited consideration to communal arrays on public buildings, in which local residents have a stake; to large (≥ 30 KwP) arrays on commercial and farm buildings; and to MWp scale open field arrays.

It is evident from the relationship between PV capacity growth in Germany and the availability of financial incentives, principally the feed-in tariff (FiT), that there is a linkage: as clearly shown in Figure 1 in Chapter 1. However, as argued in that chapter, the widespread assumption that the linkage is a simple one of cause and effect risks being superficial, and thus bears examination. That is particularly so with regard to small PV systems on individual dwellings; whereas very large systems, especially MWp scale ground based arrays, are likely to be pure investments for financial return.

Consideration of how this thesis could contribute to filling this gap in the literature led to formulation of a central **hypothesis** :

H_1 Financial incentives, primarily the feed-in tariff, have catalysed the rapid build-up of PV in Germany, not so much by making it *profitable* as by making it *financeable.*

Key words used in the hypothesis are here defined as follows.

Profitable : giving the PV array owner(s) a return on investment at least 2% above that available in standard "high street" savings accounts - meaning in practice ≥5%, in recent years (see 3.2.4 below),

Financeable : a would-be purchaser of a PV system is able, by a combination of own funds and loan finance, to raise the purchase price of the system. The own funds element does not require the committing of a larger sum than for a comparably major purchase, such as of a car or home extension. Loan finance terms are such that the overall balance of costs and benefits is acceptable to the purchaser.

Notes

- 'Financeable' subsumes the concept of 'affordable', interpreted simply as being able to put together the money to pay for a PV system, from own capital plus loan financing if necessary.

- Questions of the return on investment, if any, and the payback period (time taken to recover through feed-in tariff income the total cost of PV system and financing) expected by the purchaser are complicated and vary from case to case; they are considered in 3.7.5.5 and 3.7.5.6 below.

- The return on investment of own capital will of course depend inter alia upon the percentage of PV system cost financed by borrowing. A high percentage of loan finance will tend to increase the *rate* of return on own capital invested, but reduce the actual monetary return because the capital sum involved is smaller (eg. 10% return on €1000 is less than 5% on €2500).

Similarly, the difference between the return earned by investing money in a PV system, as compared with in a savings account, will depend on the sum involved. For example, earning 3% more than from a savings account on say €2500 of own capital means €75 per annum, or a little over €6 per month extra. Whether that is material depends on individual circumstances. The converse **null hypothesis** is:

H_0 investment in PV in Germany is driven solely or overwhelmingly by the prospect of an attractive return, "profitable" as defined above.

2.2 Elements of investigation (1) : is PV capacity following the expected return?

If the null hypothesis H_0 is true, then the logical inference is that the great majority (say 80% or more) of PV capacity will be installed where the expected return on investment is higher, and at least 2% above typical savings account rate. There should in that case be a strong correlation between the size of PV capacity in a given geographical area, and the expected return on investment.

This strand of the research investigated question (a) in 2.1 above - whether the prospect of attractive return is the main driver - through examination of the null hypothesis, by means of a test for correlation between PV capacity and expected return on investment, combined with a sensitivity analysis of whether any PV capacity has been installed where expected return is low. The findings are set out in Chapter 5 section 2.

The sensitivity analysis included factors such as PV system cost (taken to be uniform across Germany), interest rate and other financing terms in a simple model to calculate expected return on investment, and thus establish approximate ranges of return for a location with a given insolation level and hence feed-in tariff income. That in turn enabled an assessment of the proportion of PV capacity which has been installed in areas where expected return is high, moderate, and low.

A detailed description of the approach taken is in Chapter 4, Method & Methodology. It involved constructing a data set of the over 1200 German communities which participated in the "Solar Bundesliga" (Solar League) in 2008-09, and over 1500 in 2010-11, incorporating for each of them the projected annual output from a PV array, as proxy for feed-in tariff income and thus return on investment. It may be that this data set will offer a useful resource for other researchers, and for local and regional governments in Germany.

2.3 Elements of investigation (2) : are there other drivers of PV installation?

This strand of the research tested the main hypothesis H_1, through a fieldwork survey in Germany, to establish to what extent other drivers of PV installation are operating. The survey was expected also to yield evidence relating to the null hypothesis H_0, as it included questions about the weight that respondents gave to return on investment as a motivator. The survey, in autumn 2010, asked residents of Germany whether they had, or wanted to get, PV, and their reasons; and, if they wanted to have PV but could not get it, what the obstacles were. It included questions to gauge respondents' level of environmental responsibility, and to capture demographic information. The survey was anonymous, both to avoid problems with the very strict German data protection laws, and to encourage greater frankness in responses. To minimise costs the survey was Web based. It yielded 400 responses.

The literature review found no comparable survey in Germany on individuals' reasons for wanting, or not wanting, a PV array. It is accordingly believed that this survey represents an original contribution to the field. The University of Magdeburg carried out a survey in four areas across central Germany of acceptance level of large scale ground based PV arrays (Zoellner et al, 2008), which was related to the present research but complementary to it. Also complementary are the biennial 'forsa' opinion polls on attitudes in Germany to renewable energy, which provide helpful context. Faiers & Neame (2006) carried out a survey in the UK which produced some insights into the views of pioneer adopters of solar energy (thermal and PV) about cost and payback time.

2.4 Elements of investigation (3) : literature review

There is not surprisingly a considerable literature on various issues relating to solar PV in Germany and more widely. The literature review presented in this thesis is correspondingly wide ranging, covering the following dimensions.

- Recent history of German government policy on PV and mechanisms to support its development; the reasons for that support, and for the choice of the feed-in tariff rather than of a quota based approach.

- Linkage between incentives for PV installation and level of demand for PV.
- Socio-psychological components of German residents' desire to install PV, including: environmental consciousness and its effect on behaviour; consumers' perception of benefit vs cost of large purchases, especially over longer time-frames ; take-up of 'green' electricity tariffs; applicability of innovation diffusion theory; influence of local renewable energy promotion initiatives.

2.5 Elements of investigation (4) : obstacles to growth of PV capacity

To establish a baseline for assessing the outlook for PV in Germany in the next 5-10 years, it is necessary also to identify existing and potential obstacles and constraints which could limit its further growth. Candidates include the following.

- Politics, especially since the change of federal government in autumn 2009. Key issues are attempts by supporters of the established electricity supply system to cut incentives for PV, and to secure an extension of nuclear power plant operating lifetimes.
- Space constraints: the number of suitable rooftops available on which to install further PV capacity ; possible limitations on large scale arrays.
- Supply of PV modules, including the effect of increasing demand in other markets, and growth of production capacity.
- Availability of financing for PV arrays: effect of recession, credit crunch.
- Possible change in Germans' attitudes towards renewables, especially PV.

2.6 Elements of investigation (5) : outlook to 2020

The research pulls together the various strands described above, to evaluate the outlook for PV in Germany up to 2020, and most particularly to put forward an answer to the primary thesis question: whether the build-up of PV will continue at a similar rate. The core of that evaluation is an assessment of:

(a) to what extent analysis of the results of fieldwork survey, correlation tests and sensitivity analysis support the hypothesis and argument of the thesis ;

(b) how each of the drivers of, and obstacles to, PV build-up, as identified through the investigations referred to in 2.2-2.5 above, is likely to evolve.

The analysis and conclusions also take into account the wider international context, and other factors which appear significant:

- EU and international politics, especially with reference to climate change and greenhouse gas emissions reduction ;
- advances in PV technology and manufacturing, including module efficiency and production scale, and their effects on array price and output achievable from a given roof space, hence on total feasible installed capacity;
- when PV will achieve "grid parity", i.e. when will the imputed cost per kWh of electricity from a PV array equal that of a kWh bought at grid retail price, and the effects of that on demand for PV and on the feed-in tariff incentive mechanism.

Finally, some suggestions are offered for further research.

Chapter 3 : critical review of the literature

"Germany is a classic illustration that renewable energies can be the answer to a large country's energy dependency. Courageous programs have been put in place and gained the support of both the population and the private sector. Today, Germany is a leader in the development of renewable energy and delivers a positive message to other large countries that did not yet take the step to shift their energy policies towards green energies."

Gastal (2007)

3.1 Introduction

The topic is as set out in 1.1 above: will the build-up of solar photovoltaic (PV) capacity in Germany continue at a rate similar to that of the past few years? The following two sub-questions flowing from that describe the focus of the research.

(a) Why has PV capacity grown at such a rate in Germany ?

(b) What is the outlook for the next 5-10 years, say to 2020 ?

The primary focus is on small rooftop PV systems on individual dwellings, whether houses (detached, semi-detached, terrace) or apartments in blocks, and whether owned or rented. As wider context, systems on public, commercial and farm buildings, and ground-based arrays, will to an extent also be considered.

In testing the hypothesis that the prospect of lucrative return on investment thanks to the feed-in tariff is not the sole driver of the growth of PV capacity in Germany, it is clearly important to consider what other drivers there may be. There is a vast literature on topics which could potentially relate to this research, but little of it directly addresses the reasons for PV growth in Germany. The literature is especially lacking with respect to question (a) above. The issue of *why* people buy PV arrays is clearly central to an assessment of the extent to which they will continue to do so. The literature, however, barely gets beyond an implicit assumption that it is simply to do with money: that "subsidies" impel, as it were 'bribe', people to invest in PV.

A more rigorous analysis is needed of the relative importance of financial incentives and of other factors relating to socio-psychological aspects of PV adoption. There is much research, going back decades, on the psychology of pro-environment behaviour ; but little if any focussed specifically on solar PV. The present research aims to make a contribution in particular to filling those gaps. It seeks also to extend existing research on the context and on the outlook.

Structure of this review

The review is in the following three sections.

(a) The degree of linkage between government support for, and the evolution of demand for, renewable energy.

(b) The history of government support for development of renewable energy sources, and PV in particular; and reasons for that support - why did the German government provide it, and choose the feed-in tariff approach?

(c) Socio-psychological theory in relation to adoption of PV, including innovation diffusion theory, and environment consciousness as a possible driver of PV demand.

The research question is broad ; so, correspondingly, are the literature and this review of it. The review includes a section on the history to provide context for an understanding of what has happened, and of the outlook with regard to reasons for and drivers of growth of PV capacity in Germany. That said, it would not have been difficult to include at least as many literature references again. To keep the length of the thesis within bounds, this review seeks to cover a representative selection from the literature by picking out previous research relevant to the thesis topic.

3.2 : Linkage between support and demand for PV

3.2.1 The effect of feed-in tariffs

As noted in the Introductory chapter, the literature contains many references to "generous subsidies" for PV, a phrase so frequently used as almost to have become a cliché. Such references imply and in some cases explicitly state a simple cause-effect linkage between support and demand, the latter driven purely by the prospect of financial gain. A notably blunt formulation is that by Mints already cited in Chapter 1 above: ".... demand for photovoltaic products exists because of subsidies, and would not exist without them." (Mints, 2006). That is strictly speaking an overstatement, since people have been buying photovoltaic products for decades, albeit in relatively small quantities.

It is, however, clear from the evolution of various PV markets, particularly in the last decade, that there is a quite strong linkage between the existence of support mechanisms, especially feed-in tariffs, and both the extent and rate of build-up of installed PV capacity. Flynn & Bradford (2006) put it in neutral terms: "The industry's rapid expansion is directly linked to government support programmes". In the case of Germany, this is apparent in charts of the growth in capacity up to 2009, such as Figure 5 below (similar to Figure 1 in Chapter 1, but beginning in 1990).

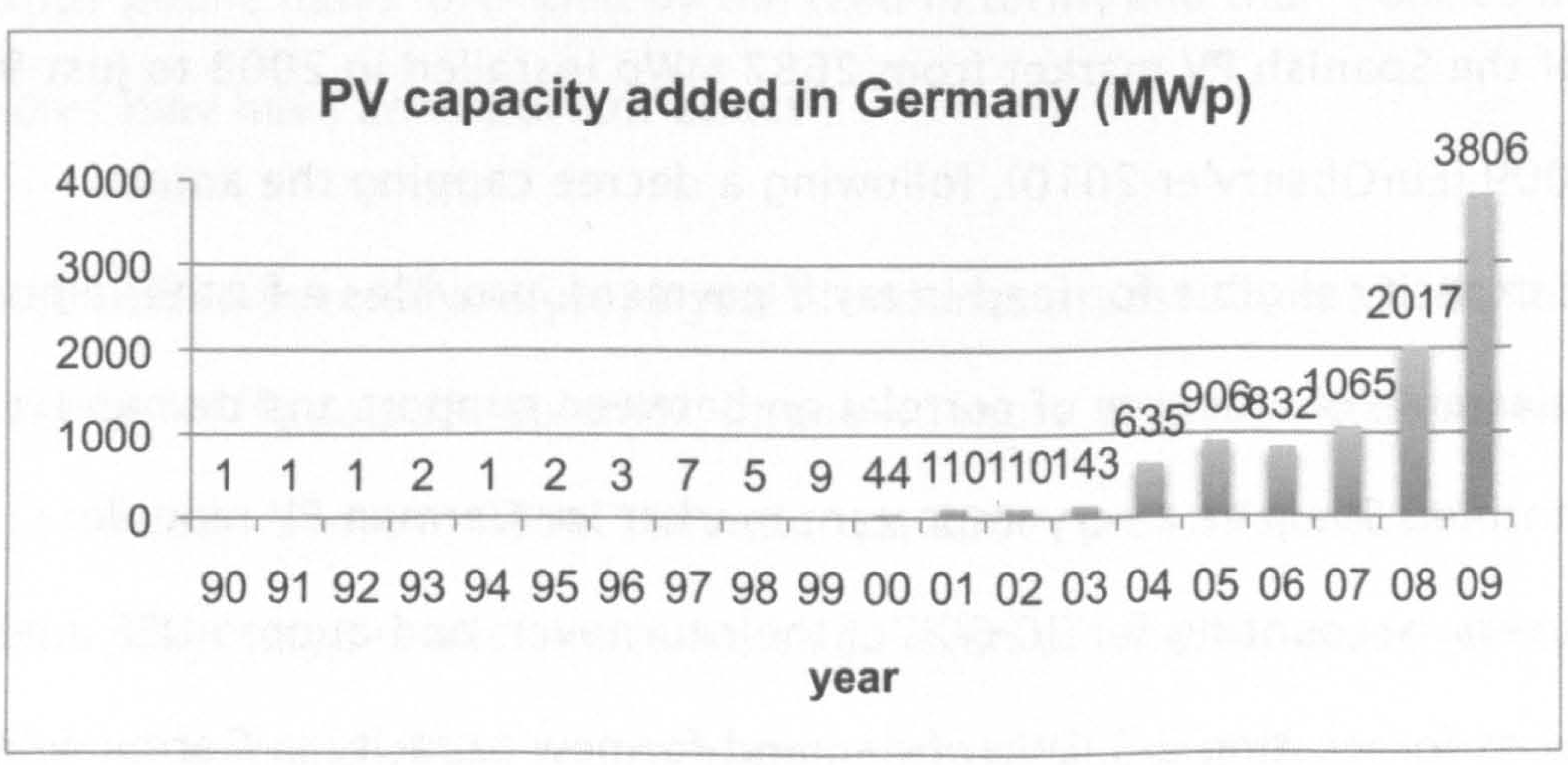


Figure 5: new PV capacity installed in Germany, 1990-2009 ; data from German federal environment ministry, BMU (2009a)

Two turning points are discernible: substantial jumps in the annual level of new PV capacity installation from 2000, when the first Renewable Energy Sources Law (EEG) came into operation; and even more markedly following the increase in feed-in tariff rates under the revised EEG of 2004. As Jäger-Waldau (2005) put it, that "resulted in a dramatic increase in PV installations".

The 2005 annual report of the IEA PV Power Systems Programme (IEA-PVPS 2005b) contains an interesting insight in its review of Germany's PV incentives: "The programmes described above have *accelerated* the installation of PV systems in Germany significantly." (emphasis added). That implies that the programmes did not of themselves *create* the demand for PV. On the other hand, according to the IEA Trends Report in the same year the purpose of support for PV was "to push price reductions, by forcing manufacturers to install additional production capacity to meet a somewhat artificial demand" (IEA, 2005).

The German solar industry association has linked increasing demand for PV worldwide to the introduction in ever more countries of support mechanisms on the German model, i.e. feed-in tariffs (BSW, 2008a). Such a relationship is emerging in the UK following the introduction of its feed-in tariff in April 2010, as reported for example in Jones (2010). IMS Research, quoted in Photovoltaik (2010a) predict strong growth in the UK market as a result of the FiT. The collapse of the Spanish PV market from 2687 MWp installed in 2008 to just 99 MWp in 2009 (EurObserv'er 2010), following a decree capping the annual additional capacity eligible for feed-in tariff payment, provides a further albeit converse example of a degree of correlation between support and demand. Lill (2008) identified Spain as a very important market for German PV module manufacturers, accounting for 30-60% of their turnover; and quoted UBS analyst P. Hummel as forecasting 2-3 GWp of demand for new capacity in Germany in

2009, which might thereby absorb module production no longer taken up in Spain. In the event, new capacity installed in Germany in 2009 was 3.8 GWp.

Many references in the literature are, however, rather uncritical, implying that the support-demand linkage is simply to do with installation of PV purely as a money-making investment, as though governments were promoting adoption by making PV such a lucrative proposition that anyone with a modicum of sense would be bound to get in on it. That may be so in the case of professional investors who take a share in funding of MWp scale ground based PV arrays or large systems on commercial rooftops, and whose primary motivation one may reasonably assume to be what they consider a satisfactory combination of return on investment and level of risk. As regards other segments of the PV market, however, this thesis argues that the linkage is somewhat more subtle, and that feed-in tariff or other support mechanisms are a necessary, but not on their own sufficient, factor in driving build-up of PV capacity.

3.2.2 Only in it for the money?

As noted above, numerous commentators use phrases such as "generous subsidies" in referring to feed-in tariffs. For example, Lund (2006) finds that the high penetration rate of PV in Germany could "directly be associated with the generous public hand" provided by the feed-in tariff, and that "Policies and subsidies may have an important effect".

Prominent feed-in tariff analyst Miguel Mendonça assessed that in Germany "The increase in tariffs paid for solar PV [made it] more attractive commercially and [led] to a solar boom in 2004." (Mendonça, 2007, p.35). The word "commercially" implies a businesslike calculation of whether investment is worthwhile, in terms of the return in prospect. He appears to view individual householders as applying a similar test: ".... alternatives [to FiTs] do not offer householders to receive a sufficient rate of return to make investment worthwhile." (op cit, p.16).

Bröer (2007) states baldly that without the Renewable Energy Sources Law (EEG) "there would be no PV market in Germany". He does not, however, refer to enticing returns on investment; rather to feed-in tariff support covering the "added cost" of PV as against Grid electricity, and thus making installation economic, the sense of that word here seeming to be that of a financeable proposition. A spokesman for major German PV company Q-Cells put it plainly at the Intersolar trade fair in 2007, that: "The feed-in tariff changed everything - it is that simple." (quoted in The Guardian, 2007). Speaking at the Industry Forum during the 21st European Photovoltaic Solar Energy Conference (PVSEC) in Dresden in 2006, the CEO of Q-Cells, Anton Milner, expressed the view that 80-90% of PV installations depend on feed-in tariff or subsidies (reported in Gunther, 2006; and author was present). He did not elaborate on the remaining 10-20% of installations, nor on the nature of "subsidies"; nor did he clarify whether a FiT rate which also provides a return on investment is required. A plausible inference is that 10-20% of PV installations would take place even without a FiT, or at least one at the prevailing rate, which is consistent with the hypothesis that there are other drivers of PV uptake than profitability.

In the assessment of Stryi-Hipp (2004) the increase in the German PV feed-in tariff, under the first EEG in 2000, from the previous 8.5€¢ to 50.62€¢ per kWh meant that "the economic situation for investors was dramatically improved". His use of the word "economic" similarly seems to imply a commercial evaluation of the merits of installing PV, focussed on return on investment. As Figure 5 above shows, the absolute increase in annual new capacity installed in Germany from 2000 was not as great as that from 2004, although similar in percentage terms.

Yet the revised EEG of 2004 did not increase the PV feed-in tariff "dramatically"; it rose some 13% to 57.4€¢ per kWh, while capacity installed rose by 344% in 2004 over 2003. There is of course an interplay between feed-in tariff rate and PV system cost which influences projected return on investment. See 5.2 below on that aspect. Suffice it to note at this point that PV system prices remained stable from 2003 to 2004.

In 2006, industry analyst Pramodh Panchanadam of Frost & Sullivan said that to sustain growth the PV industry needed "to pull away from a subsidy supported to market driven entity" (quoted in Renewable Energy World, 2006). Speaking in 2008, venture capitalist Neal Dikeman saw PV as "a niche subsidized business" (quoted in Vogler, 2008).

Consistent with linkage of demand for PV to the feed-in tariff, the supplementary in-year cut of 16% in the German FiT rate in 2010 was predicted to reduce demand. For example, Henning Wicht, principal market analyst at iSuppli, predicted a "collapse" in the second quarter of the year, because cuts in "solar subsidies" would make PV less attractive (Wicht, 2010a). EuPD Research (2010a) attribute the considerable jump in first quarter installations, tenfold over Q1 2009 to 714 MWp, to anticipation of FiT rate cuts pulling forward demand. Nonetheless, many small systems of ≤10 kWp were installed in July-September 2010, after the 13% first stage of the FiT cut: 23,557 in total, pro rata not substantially down on the 58,388 installed in January-July (federal grid agency data).

Yang (2010) concludes that rapid growth in demand for PV will not be sustainable unless "governments continue and expand their financial incentives", giving the examples of the German feed-in tariff and "generous" (that word again) feed-in tariff in Spain. Further examples appear frequently, for instance in Shon-Roy & Wiesnoski (2010): "The cost of solar cell energy is still considerably higher than other forms of energy, especially when taking into account the large amount of government funding going into solar". That overlooks subsidies to fossil and nuclear energy, and their externalities not factored into cost comparisons (see for example UNEP, 2011).

3.2.3 Subsidies?

A further representative example of broad brush statements of support-demand linkage is in Elliott (2003): ".... much more generous subsidy arrangements .... such as the .... feed in tariff system in Germany .... have unsurprisingly led to the rapid deployment of renewable energy". Savitz (2008) refers repeatedly to "subsidies" and to "... the need to prop up the industry on the backs of taxpayers", and specifically in the case of Germany to PV growth being "... thanks to the generosity of the German taxpayer" and "lucrative feed-in tariff". The role of the German FiT was acknowledged in 2008 by Colin Stone, a fund manager with Fidelity Investments, in similar terms as quoted in Collinson (2008): ".... the application of early government spending has helped to jump start this industry. Without the subsidies, the whole industry would be many years behind in reaching grid parity.". Such imprecise terminology suggests a lack of understanding of how the German feed-in tariff system operates.

If one discounts the legislative and administrative work involved in designing and operating the system, since that applies to support and regulation of any energy source, no tax revenue is devoted to feed-in tariff schemes other than minimal sums for printing of information material. The cost of the FiT payments themselves is shared across all electricity users through their bills, although "energy intensive industries" contribute very little thanks to special treatment. Thus, as Milford (2007) puts it, "the market relied on significant support from the German consumer", not from public funds. Lund (2007) analyses the "direct cost to the public sector" of various renewable energy support measures, yet finds that feed-in tariffs are "clearly the most expensive"; perhaps based on an unconventional definition of "public sector" as including consumers, not only public expenditure of taxpayer money.

The distinction may appear subtle, given that the vast majority of taxpayers, bar a few living off-grid, are also electricity consumers. However, it mattered when the established electricity industry mounted a legal challenge to the first Renewable Energy Sources Law (EEG) of 2000. The European Court of Justice ruled in 2001 (in PreussenElektra vs Schleswag AG) that Germany's feed-in tariff scheme, laid down in its Renewable Energy Sources Law (German acronym EEG), does not constitute 'State aid'.

It is debatable whether "subsidy" is an applicable description of feed-in tariff payments to operators of PV arrays. Bechberger et al (2003) note the opinion expressed among EU competition authorities and in the literature, that because feed-in tariff payments are legally required, albeit made by electricity consumers, they can be considered subsidies. It could also be argued that the payments constitute a "subsidy" in the sense that they help to make it possible for people to buy something, namely PV systems. However, they differ from price subsidies for essential items such as flour or kerosene. They are, rather, a key element in a market promotion programme aimed at building up PV capacity, in pursuit of national and international goals: cutting carbon emissions in the energy sector, reduction of dependency on imported fuels, and industrial policy relating to employment, exports and regional regeneration. (The reasons for the German government's support of renewable energy including solar PV are addressed in section 3.4 below.) At any event, as noted in EPIA (2005), a feed-in tariff does not create a burden on a State's budget, unlike investment subsidies or tax rebates.

Mendonça (2007) describes the feed-in model as a "pricing law", under which renewable energy producers receive a set rate for electricity which guarantees profitable operation for a set period, and priority Grid access. He lists among its advantages (op cit, p.13):

- the most successful approach yet found to developing markets for renewable energy and to achieving associated social, economic, environmental and security benefits
- encourages steady growth of small- and medium-scale producers
- ease of entry
- flexible enough to adjust to technology and market changes.

German parliamentarian Hans-Josef Fell (Greens), one of the architects of its feed-in tariff, spoke at the 23rd European Photovoltaic Solar Energy Conference (PVSEC) in Valencia 2008 of the need for support systems to be consistent over a sufficient period. The German FiT mechanism has been successful not solely because it provides financial support, but also because it has not suffered "stop-go" changes and swings, thereby giving planning security and investor confidence; reported in Hand (2008b). Wiser et al (2007) find that sustained long term support programmes may enable greater reductions in PV cost.

3.2.4 Generous?

Are feed-in tariffs "generous"? Claims of "dream returns" and "lucrative" investment in PV need to be treated with caution, as not all comments are necessarily objective and some vested interests are not above exaggeration. As Berger (2001) put it, although financial incentives are needed to make investment in PV more attractive, they should only be enough "to stimulate potential adopters for an actual purchase without distributing gifts". Madlener and Stagl (2000) note that it is "... very difficult to find (and to regularly adjust) an optimal tariff level for each of the renewable energy technologies included in the scheme that avoids excessive profit margins, enhances at least some degree of economic efficiency, and promotes all technologies in the way and to the extent desired.".

According to Stryi-Hipp (2004), the German solar industry association calculated the desired PV feed-in tariff (FiT) as between 49-59€¢ per kWh, on the basis of system cost (which tends to be lower per kWp capacity for larger systems) and an average return on investment of 6.5% in southern regions of Germany. The actual FiT rate introduced of 57.4€¢ for small PV systems is very much in line with that. This is significant for two reasons.

Firstly, for much of the decade such a level of return was not greatly above typical interest earned in risk-free 'high street' savings accounts, which it seems reasonable to expect individual householders considering PV to take as the comparison benchmark. No single archive of interest rates was found, but samples from individual sources indicate a range of 2.5-4.0% for fixed term savings bonds. Stiftung Warentest, the German equivalent of Which?, found a typical rate in 2004 of 3.75% for a one year fixed rate bond. The author's savings account at HVB bank in Munich was paying 4.0% in 2007 and 3.45% in 2008. Even in 2010 fixed term bonds were offering 2.5-3.75% (Finanzen.de, 2010).

Secondly, solar radiation level (insolation) and hence projected electricity output from a PV system of given size are higher in the south of Germany. Since return on investment (RoI) depends primarily on the interplay between FiT rate and therefore projected income, and PV system price, it will at a given price level broadly correlate with system output and accordingly in central and northern areas of Germany be lower than the predicted 6.5% referred to by Stryi-Hipp (op cit). See Chapter 5.2 for the results of a sensitivity analysis of expected RoI.

Lauber & Mez (2004) describe the FiT increase from 2004 as making PV "commercially attractive without additional support", but do not indicate a range of anticipated return on investment. Schlandt (2009) talks of installation of PV on the roof as having become "significantly more lucrative", in the "generously subsidised German market", as a result of falling system prices. He quotes SunForFree GmbH (Ltd) as estimating returns at 6-7%. Prominent weekly news magazine Der Spiegel (2009a) writes similarly of PV systems never having been so attractive, putting the anticipated "dream return" on investment at 5-8%, depending of course on system price and annual electricity output. Hartmann & Haberer (2010) put the return at "nearly 5%, before tax". Daily & McBride (2010) state that solar power plant developers in Germany "typically earn about 8% returns", which is not remarkable bearing in mind that these are large, often MW scale, projects with lower unit prices for PV modules. Muller & Yurtoglu (1998) noted that in the period 1985-96 German companies achieved significantly lower returns than did US and UK firms, which might indicate a generally lower expectation of return on investment in German thinking.

The editor of 'Photovoltaik' magazine, Michael Fuhs, laments the relatively modest increase from 2008 to 2009 of 16% in PV capacity installed in Germany in small systems, meaning those under 10 kWp, which are almost all on individual house or apartment block roofs (Fuhs, 2010a). He argues that it is because in many cases the return on investment is not high enough. In the same issue he puts the typical return at 4-7%, and advances the reasoning that "PV arrays must promise higher returns to be economically attractive", because they "always involve a certain risk" (author's translation). He does not elaborate on what risk might be involved in an investment backed by legally guaranteed feed-in tariff income. As e.g. Friedlob & Plewa (1996) observe, companies seek higher returns than available from savings accounts, to justify the risk involved in doing business. Since installing PV involves minimal risk, thanks to guaranteed FiT income, financing and insurance, expectations of return on investment should not be high.

The feed-in tariff in France has been comparable to Germany's, but a farmer quoted in Trompiz (2009) describes the return on investment in PV as "decent enough but not extraordinary", adding that the motivation "is more like to have an extra retirement pension". Jager (2006) points out that although grants available for PV in the Netherlands from 2001-2003 covered 90% of cost, offering a simple payback time of 3 years, take-up was relatively modest.

It is noteworthy that estimates of return on investment in PV are all in a similar range, 4–8%. Against this background, it does not seem entirely appropriate to describe returns on investment in PV, at least by householders, as "lucrative"; nor, accordingly, the FiT rates as "generous" in comparison with the savings account range of 2.5–4% referred to above.

As Koot (2008) points out, demand for PV in Germany continued to grow notwithstanding the annual 5% reduction ("degression") in the FiT rate for new installations. Indeed, growth went on increasing even after the government increased the annual degression to 8% from 2008 to 2009, and 9% from 2009 to 2010 (for small systems). The degression was from the start intended to encourage manufacturers to achieve corresponding reductions in PV system costs. They have done so, as the 'experience curve' shows, apart from an upward blip in module prices owing to the shortage of solar grade silicon in 2006-08.

A question very relevant to the research presented in this thesis is: what level of expected return on investment, if any, is needed to impel individual householders to decide to install PV systems? Erge et al (2001) acknowledge that people who had before then installed PV, despite its high cost relative to Grid electricity, must have had other motivations: demonstrating their convictions to others, environmental concerns, anticipating that electricity prices will rise, using PV as a building element to save cost, and availability of financing schemes to help meet the cost of installing PV. They conclude, however, that for large scale adoption of PV the main incentives must be "cost reduction and reasonable funding", referring to rate based incentives (i.e. feed-in tariffs) as such a measure.

The head of the German solar energy promotion association SFV defines a "cost-covering feed-in tariff" as providing variously "a reasonable return on investment" after covering all costs, and "a return .... equal to that of other types of investment" (von Fabeck, 2008a). He does not specify what those other types might be; a reasonable inference in the case of individual householders is a comparison with savings accounts.

Blake (2008) uses the phrase "a healthy profit", and quotes German architect Rolf Disch as saying that "It used to be only idealists who were interested in solar. But now there's money to be made from the sun.". Commenting on Blake's article, Michel (2008) expresses the opinion that "The approximately 450,000 operators of renewable energy installations [in Germany] do it generally to make money.". None, however, expands upon the motivation. A legitimate question is, *to what end* do people who install PV wish to earn feed-in tariff income from it? Candidates include: purely as a profit making investment; or in order to recover the cost of a PV system, that they wish to have for other reasons. As Koenemann (2006) puts it, the prospect thanks to the feed-in tariff that installing PV on one's roof would *not only* do something for the environment, but *possibly also* earn some money [emphasis added] changed attitudes to PV throughout Germany. Comments quoted in Fuhs (2010b) from Umweltbank ("Environment Bank"), which makes loans for PV installation, are interesting: their first customers were environmentalists, not much concerned about return on investment; then in 2007 people who valued independence from electricity suppliers; and in 2008 the media aroused desire for return on investment. The view of Frankfurter Allgemeine journalist Heeg (2010) is that people in Germany install PV not because they are especially environment conscious, but in pursuit of investment returns "up to double figures"; though that may reflect conventional economic thinking in a newspaper based in Germany's financial centre, perhaps also with the concerns of professional investors primarily in mind.

Weng (2004) sets out a range of factors affecting whether the projected return on investment is "sufficiently high", and comments that "most investments in PV in suitable locations make economic sense". He presents a worked example of a 35 kWp PV system on the roof of commercial premises, arriving at an Internal Rate of Return (IRR) of about 10%. It is, however, open to question whether individual householders use IRR calculations, rather than simple payback. As Yang (2010) observes, commercial customers are likely to place more emphasis on cost-effectiveness than residential users. Markus Lohr of PV market research firm EuPD Research said in an interview in June 2010 (quoted in Photovoltaik, 2010b) that it is not meaningful for a private investor to think in terms of internal rate of return, like an investor in a ground based PV array would. This issue will be explored in Section 3.7 below on socio-psychological aspects.

A 2009 survey in the UK, reported in New Energy Focus (2009), found that 90% of householders would consider investing in PV if the feed-in tariff rate was set at or above 50p per kWh. Such a rate would provide a return fairly describable as "generous". Plater (2009) concluded that the then proposed rate for small PV systems of 36.5p per kWh would be generous in terms of simple return, in the region of 4-5% tax-free and index linked, allowing for full capital payback.

There is otherwise a dearth of research into what motivates individual householders to install PV on their roofs. References to linkage between support mechanisms, primarily feed-in tariffs, and demand for PV generally employ terms such as "investment" and "returns" in a rather indiscriminate way. A recent example is Mints (2010a), who states that the German feed-in tariff "provided an economic motive for installing a photovoltaic system". The implication, that householders too are economically rational actors, who base their decision on the same criteria as professional investors, needs investigation. No commentator appears to have considered the possibility that support mechanisms such as feed-in tariffs produce at least part of their effect by enabling, rather than causing, purchase of PV systems, thereby unleashing existing but latent demand. This thesis seeks to make a contribution to closing this lacuna in knowledge.

Fuhs (2010a) observes that the customer "is the great unknown", and that calculation of expected return on investment is unpredictable because sensitive to PV system cost. He does not, however, investigate why, if economic logic is against doing so, there are still increasing numbers of householders installing PV. The implication is, in line with the hypothesis argued in this thesis, that there are other drivers besides pure profitability. As Shum & Watanabe (2007, p.1188) observe, ".... no single factor will explain the driving forces for residents to install PV systems". They suggest a combination of environmental awareness, "subsidies", and the possibility of selling electricity back to utilities (which could mean a feed-in tariff or net metering at suitable rate).

Shove & Warde (2002) identify one candidate: being a "green consumer .... who seeks out the most environmentally friendly alternatives or who looks for less harmful ways of meeting his of her own private needs.". They also note, citing Dard (1986), that "social comparison could prompt the installation of solar panels"; and social norms including the example of neighbours may well indeed be among the drivers of PV adoption. There is an extensive literature on the socio-psychology of pro-environment behaviours. Much of it is, however, concerned with repeated actions such as recycling, buying organic foodstuffs, and energy efficiency. There is little directly about solar energy, and that focused on installation of solar thermal collectors, with the exception of Zoellner et al (2008) who looked at public acceptance of large ground-based PV arrays.

Another possible driver of PV adoption is social change, in relation to the country's energy supply system, encouraged by mistrust of the large electricity companies and the nuclear power lobby. McKechnie & Welsh (2002) describe how loss of faith in specific institutions can lead citizens to withdraw from quiescent support, and drive social change. In the case of PV, that may be manifested in a desire for independence from electricity utilities, providing motivation to own a PV system - albeit grid connected rather than, as yet, a self sufficient supply.

As pointed out in SFV (2010a), if reducing the FiT rate impacts upon demand such that manufacturers are obliged to drop prices, their profit margins and hence ability to invest in production capacity and R&D will suffer. Such a FiT rate cut pushes down selling prices and company revenue, not production costs.

3.3 History

"On April 1st, 2000, the renewable energy law went into effect, and the triumphal procession of the photovoltaic industry could begin."

co-architect of that law Hans-Josef Fell (2005)

3.3.1 What, why and how

In examining the development of demand for PV, hence of the PV market, in Germany there are three elements to consider: *what* government has done, *why* it did it, and *how* far it has driven the build-up of demand and installed PV capacity. This section addresses the first of those questions, as the context for later discussion of the reasons for German policy, and its role as a driver of the build-up of PV capacity. Jackson (2008) stresses the importance of policy in shaping the social context, as "Governments influence and co-create the culture of consumption in various ways".

There is an issue of definition here, namely what we mean by "government". Germany is a federal state comprising 16 'Länder', which one may translate as "regions", although three of them are the relatively small areas around cities - Berlin, Hamburg and Bremen. The non-city Länder are further divided into sub-regions (Bezirke), broadly similar to English counties. Accordingly, "government" can have several meanings: at Federal, Land, sub-region and even city level. Most research in the literature on support for PV concentrates on the Federal level, though some authors include certain cases of Land and city support, eg Berger (2001), Lauber & Mez (2004).

A substantial addition to the literature on history of PV support in Germany is Jacobsson & Lauber (2006). Their paper does not set out a fully detailed history, but ably describes the evolution of German government policy on renewable energy, with specific reference to wind and PV. It ranges from the "formative phase" from 1974 to the late 1980s, through policies from 1988 to promote a market for renewables, to the present greatly increased market. The literature appears still to lack a comprehensive treatment of support at all levels, including the reasons for its introduction. The following account may contribute some input to such a full history.

3.3.2 From the early stages up to 2000

Various authors refer to the earliest roots of support for renewable energy in Germany as being in the oil crisis of 1973. Wüstenhagen & Bilharz (2006) additionally identify the 1974 campaign in south-western Germany against the proposal to build a nuclear plant at Wyhl, showing how that led to Freiburg im Breisgau's development as a leading green and especially solar energy centre, and to the origins of the Green Party. Freiburg was the first, and until 2006 only, city of 100,000+ residents to have a Green mayor (Dieter Salomon).

It is interesting that up to the mid 1980s the political climate in Germany was still strongly in favour of coal and nuclear power, and renewable energy sources were largely neglected. However, institutional changes occurred which opened up for wind and PV "a space which proved to be of critical importance for the future diffusion" (Jacobsson & Lauber 2006), through R&D programmes. In the 1970s and 1980s Germany was the largest spender in the EU on renewable energy R&D, some one third of that money going to PV (Blok 2006). Wüstenhagen & Bilharz (2006) observe that public opinion surveys conducted at intervals from 1984-2003 showed increasing support for renewables, with solar the most popular (BPA 2003).

Jacobsson & Lauber (2006) make the point that advocacy coalitions for renewable energy, particularly PV, grew from the late 1970s with the founding of BSI (Bundesverband der Solar Industrie, now B. der Solar Wirtschaft, both meaning "Federal Association of the Solar Industry") and of the Öko-Institut in Freiburg im Breisgau, both in 1977 ; of the Förderverein Solarenergie ("Association for Promotion of Solar Energy", now called SFV) in 1986 ; and of Eurosolar in 1988, among whose members are German members of parliament from various parties.

The key turning point was in 1986. The disastrous nuclear reactor accident at Chernobyl shifted German public opinion from 50:50 to 70:10 against nuclear power with 20% undecided (Jacobsson & Lauber 2006). That eventually led to the 2002 law requiring phase-out of all nuclear power stations by 2021; a target which was, however, called into doubt by the new right of centre government's action in late 2010 to permit extended operating lifetimes for nuclear plants (see Chapter 6.1). In addition, the government of Helmut Kohl (1982-) focussed on the climate change threat, and the need in response to it to transform the energy supply system. The Rio conference in 1992 reinforced that. Sawin (2004a) assesses the drivers of the first Renewable Energy Sources Law in 1990 as growing public concern over nuclear power safety (without, however, mentioning Chernobyl), the environmental impacts of energy supply including climate change, and additionally security of energy supply.

The advocacy coalition supporting development of renewable energy continued to strengthen following Chernobyl and the UN Conference in Rio, extending to churches, farmers, the VDMA machine builders industry association, and even some CDU/CSU MPs. Sawin (2004b) makes a similar point about support for renewables, and especially feed-in tariffs, having created a pro-renewables constituency. She adds to it lawyers, union workers, landowners, construction companies and banks. Berger (2001) takes a wider view of the 'players' involved in renewable energy diffusion, extending quite reasonably to potential adopters, installers and suppliers of systems. Agnolucci (2008) observes that the EEG 2000 boosted support for PV, thus adding large numbers of owners of small PV systems to the advocacy coalition.

Maycock (1995) made what proved to be a very accurate prediction: "Government policy will dramatically shape the future. Environmental concerns, social costs of non-renewable options, and the cost of oil and gas will contribute to expanded markets. Costs must be reduced, large plants constructed, and profits made before the photovoltaics option can become a serious energy supply option. The focus is on Europe as the post-Chernobyl era couples with Green politics to create an environmentally benign, fully economic photovoltaics.". For the wider European context, a detailed review of the EU's promotion of renewable energy can be found in Mancisidor et al (2009).

The major waypoints on Germany's road from the immediate Chernobyl aftermath to 2005 are well chronicled in Jacobsson & Lauber (2006). Bechberger & Reiche (2004) provide a helpful account of German government measures to promote renewables from 1989-2003, identifying the influence of the coal sector including within the SPD as an obstacle to renewable energy growth, and as a positive development the transfer of responsibility for renewables from the economics to the environment ministry, at the Greens' demand after the 2002 election. The 1000 solar roofs programme and the first Electricity Feed-in Law both date to 1988. Hänel et al (2004) note that prior to 1990 there was no regulatory framework in Germany for grid connection of PV arrays, which up to that point were mostly private stand-alone systems. Local initiatives in some Länder and cities are described in for example Haas (2003), Berger (2001), and Erge et al (2001) on demonstration programmes at schools.

Those local initiatives were relatively minor in scale, but important in their effects by ensuring that enough of a market for PV continued to exist, and thus attracting companies to produce PV in Germany, to keep the embryonic industry going: "... even modest support was enough to create a space for wind and solar power to start out on a formative period" (Jacobsson & Lauber 2006). Gutermuth (1998) saw even small scale support as having a significant psychological impact, as a signal to would-be adopters and investors that the State stood behind renewable energy. Lauber & Mez (2004) make the same points about the influence of Chernobyl, and how initially modest support for PV preserved enough "market spaces" for it to develop, and increase its legitimacy and advocacy coalition. Milford (2007) sees even the low level of demand for PV prior to 2000 as having given manufacturers and installers valuable practical experience, and increased public understanding of the technology, thus contributing the foundations for later rapid growth. Wüstenhagen & Bilharz (2006) add the insight that prior to liberalisation of the electricity market, the supply structure was often owned by local communities, which helped sustain local level support for PV through feed-in tariff schemes.

Berger (2001) covers the pre-2000 history of PV support in Germany in a good deal of detail. He sees the 1000 Roofs programme in particular as having been "a catalyst for the diffusion process". The detailed analysis by McVeigh et al (2000) found that market penetration by renewables up to then had been below expectations, although they had achieved better than expected cost reductions. Blok (2006) comments that the German government timed skilfully the shift from support for R&D to support for market deployment. Hoffmann (2005) presented a somewhat less positive view: that because the 1000 Roofs programme had a capped budget which ran out after three years instead of the planned five, its 'stop-go' support caused investor uncertainty, an experience repeated by the 100,000 Roofs programme of 1999, whose target of 300 MWp installed capacity was reached a year earlier than expected. The government learnt from these lessons in creating the 2000 and then 2004 improved EEG. As Hoffmann explains, conditions thereby for the first time became positive for long term business planning; and the German PV industry showed its true strength.

The period of modest demand continued until the advent of the "Red-Green" coalition government of SPD and Greens in 1998, which brought enhanced support programmes: after the 100,000 Roofs programme of 1999, it enacted the Renewable Energy Sources Law (EEG) in 2000, which included a significantly enhanced feed-in tariff (FIT) for PV. As for instance Milford (2007) notes, the original FIT of 1991 was set at the same rate for all renewable sources, the DM equivalent of €0.085 per kWh: enough to make wind viable, but not PV. The solar energy promotion association SFV claims to have been the first to propose, as far back as 1989, a feed-in tariff at a level which would cover the cost of installing and operating a renewable energy system and provide a reasonable return on investment (von Fabeck, 2008a). Following introduction of such an incentive in a series of German cities, it was enshrined in law in EEG 2000.

3.3.3 Developments since EEG 2000

Those SPD-Green measures, in particular the improved 2004 EEG, undoubtedly contributed to a considerable extent to rapid expansion of the market. It is, however, the contention of this thesis that there is not such a simple 100% cause:effect linkage as most of the literature seems to assume - see section on "Drivers" below. For example, Wüstenhagen & Bilharz (2006) refer to the 100,000 Roofs programme, including financing on attractive terms, as "making PV commercially viable for the first time". This thesis argues that it would be more precise to say that the programme made PV *financeable*, especially for individuals, who are not commercial enterprises.

Berger (2001) explains how the 100,000 Roofs programme and the 2000 Renewable Energy Sources Law (EEG) overtook local initiatives – with the interesting sidelight that the 300 MWp capacity target of the nationwide 100,000 Roofs programme meant an average across the population of Germany of 3.66Wp/person, *lower* than for instance the municipal utility programme in Aachen which achieved 4.35Wp/ person. On the other hand, the 300 MWp target was reached a year early (Haug 2003), reflecting a much more rapid rate of build-up, with EEG 2000 incentives then available to provide continuing support.

The 2000 EEG provided for low-interest loans to fund grid-connected PV systems, discontinued in 2004 but compensated for in the new EEG of that year (BMU, 2004) by an increased level of feed-in tariff for PV (Bächler 2006).

Berger (op cit) also describes how local incentive programmes in the northern city states Berlin, Hamburg and Bremen led to higher PV system density there than in the sunnier south. The south, especially Bayern and Baden-Württemberg, started however to build capacity rapidly under the 100,000 Roofs programme, and now dominates in capacity in Germany : in 2005, one quarter of total *worldwide* new PV capacity went into Bayern (Sinner 2007), more than into the USA and Japan combined.

Haas (2001) lists briefly the support that Germany has provided to renewables, but does not describe the history of how that support developed. The paper also provides a succinct analysis in bullet points of the relative merits of the various support mechanisms used in EU member states. A similar listing and analysis of support mechanisms is in del Río & Gual (2004), comparing primarily feed-in tariffs (FiT) and quota based systems. Their apparently intended contrasting of FiT as "cost inefficient but highly effective for promoting [renewables capacity]", with Quota systems as "relatively inexpensive but highly ineffective", does not seem to work. If channelling money to renewable energy through a Quota approach has little effect, is it not *more* "cost inefficient" than FiT? It is, however, somewhat outside the scope of this section to examine why Germany among many other countries chose the FiT over Quota approach: see the following section 3.4 on reasons for the German government's support of PV.

Lauber & Mez (2004) describe in rather more detail developments from 1986, especially the Red-Green government's energy policy including introduction of the Eco-tax (for a fuller teatment see Beuermann & Santarius 2006), and promotion of Combined Heat & Power (CHP) for improved energy efficiency. Of particular interest is their analysis of the main political and economic actors involved in the evolution of renewable energy policy in Germany. In their assessment of the main actors, Wüstenhagen & Bilharz (2006) conclude that policy makers, especially parliamentarians, took the lead on their own initiative rather than in reaction to public opinion - which conversely then showed a high level of support for those policy decisions. Sawin (2004a) takes a different view, of public opinion influencing the actions of politicans. In any event, the growing ranks of the advocacy coalition - described, as noted above, in Jacobsson & Lauber (2006) and Sawin (2004a) - helped bolster pro-renewables politicians against the influential lobby for conventional fossil and nuclear energy. The best known of those politicians, the late Dr Hermann Scheer (an SPD, not Green, MP), described Germany's as "the first really implemented mass programme for photovoltaics" (Scheer 2004). PV has since 1998 enjoyed a 'virtuous circle' of a growing market attracting more companies to enter it, giving greater impetus to competition and technological development, in turn driving down prices. Watanabe et al (2000) identified a similar, perhaps broader, "virtuous cycle" for PV in Japan involving R&D, market growth and price reduction.

For a fascinating inside account of the politics which surrounded the enactment of the EEG in 2000 and its revision in 2004, by its co-architects, see Fell (2005) and Scheer (2008a). Points of particular interest are that EEG 2000 did not have uniform support within the SPD-Green coalition, but enough to enact it over the opposition of CDU/CSU and FDP; that by 2004 CDU/CSU opposition to the law softened, especially among their members of the Bundestag representing eastern areas desiring investment in renewables; more came to support the EEG as renewables built a critical mass of support in 2004-2007; but there was never full political and economic consensus on renewables promotion, and vested interests have repeatedly sought to roll it back, recently concentrating their attacks on PV. This is of relevance to the outlook for PV in the short to medium term: will market build-up incentives continue to command enough political support?

The revised EEG of 2004 introduced the new requirement that utilities must buy renewably generated electricity as a priority, before that from other sources

(British Embassy Berlin, 2005). This later, as renewables capacity built up, became increasingly an issue in contention between the established major electric utilities and supporters of renewable energy: see Chapter 6.

Wüstenhagen & Bilharz (2006) also identify three important factors in the development of German renewables policy: a strong central government (though without explaining how that is consistent with a federal structure); a political culture receptive to government intervention; and a critical mass of politicians with expertise in and understanding of renewable energy issues, not beholden to vested interests in the conventional energy supply system, and able to design a successful support mechanism for renewables. Such factors as the tension between big energy business-friendly ministers and the environmentalists, and the strong political influence of the major electric utilities and other large companies involved in energy supply, continue to be relevant to present and possible future developments, albeit renewable energy has meanwhile become much more firmly established.

No paper was found which notes that the effects of climate change arguably won Gerhard Schröder (SPD) the 2001 Federal election, by a very small majority over Edmund Stoiber (CSU/CDU), thanks to Schröder's telegenic and sympathy- and more importantly vote-winning pulling on of wellingtons, and wading through flood-stricken areas of eastern Germany after the Elbe burst its banks. This has more than anecdotal meaning: had victory in that election gone to the "business friendly" CDU/CSU (possibly in coalition with the similarly minded FDP), which favour a large scale centralised energy supply system based on fossil fuel and nuclear energy, the story on development of PV and other renewables could well have been very different.

CDU/CSU had another chance in the 2005 election, but failed to obtain an outright majority even with the seats of their FDP allies. The predictions of Lauber

& Mez (2004) about the election outcome and possible threat to support for renewable energy were thus not borne out. Post-election negotiations led to a Grand Coalition between the CDU/CSU and the SPD. The formal coalition agreement of 11 November 2005 included the following points on renewables:

- target of ≥20% of renewable energy in electricity supply by 2020
- continuation of the EEG, but with periodic review of whether the level of each feed-in tariff remained appropriate
- transparency in relation to the costs to electricity consumers of renewable energy support
- pursuit of international promotion of renewables, including the founding of an International Renewable Energy Agency (IRENA - achieved in 2009)
- intensification of the renewable energy export initiative.

The SPD held staunchly to the nuclear phase-out on the basis of the 2002 law stipulating it. In the run-up to the federal election of 2009, the then Environment Minister, Sigmar Gabriel (SPD) stated that no government involving the SPD would alter the phase-out of nuclear power, which did not fit with renewable energy (IWR, 2009). In the same interview, Gabriel described the EEG as "an unbelievably successful instrument" which had brought Germany a boom in renewable energy at notably low cost.

Unfortunately for Herr Gabriel and his party, the German government no longer included the SPD after the federal election of September 2009. The new right of centre German government of CDU/CSU and FDP pushed through a supplementary in-year reduction in the PV feed-in tariff, of 13% from 1 July 2010 then a further 3% from 1 October of that year. It also removed FiT support completely from ground based PV arrays on greenfield sites. The government sought to justify its action, for instance in Pfeiffer (2010) and Ruck (2010), as necessary to avoid "dream returns" and overburdening electricity users with PV support costs. This the government would do by "realigning" FiT rates with PV module prices, which fell sharply after the collapse of Spain's PV market as referred to in 3.2.1 above left a glut of modules on the market. The German government did not - or perhaps did not wish to - consider whether that was a one-off and temporary effect, and deemed it necessary to cut the PV FiT. It also acted to dilute the nuclear phase-out by extending the operating life of existing nuclear stations.

See Chapter 6 for a more detailed account of political developments in 2009-11, which of course have an important bearing on the outlook for the next 5-10 years.

3.4 Reasons for German government support of PV

"The problem of global climate change is one that affects us all, and action will only be effective if it is taken at the international level."

Margaret Thatcher, speaking at the UN in 1988

3.4.1 Introduction

The preceding section reviewed the literature on what the German government has done to support renewable energy, and solar PV in particular. This section considers what the literature says about why the German government, among others, provides such support. No single paper seen covers the whole picture; it is hoped that this section will provide a modest contribution towards doing so.

There is clear agreement in the literature, and in official sources, on the principal reasons for which the German and other governments and the European Union support development of renewable energy sources. Those "big four" reasons are:

- the environmental benefits of increasing the renewables share in electricity supply, with particular emphasis on reduction of carbon dioxide emissions to help combat the threat of climate change;
- to build up a new sector of industry, leading to increased employment and exports;
- to improve the security of energy supply;
- to help less developed countries to develop sustainably.

These reasons are not peculiar to Germany, although most other countries have woken up somewhat late to the second of them.

In addition, researchers and official sources have identified a range of further reasons for supporting renewables. Few sources refer solely to solar PV. A number, however, give prominence to it, along with wind, as the renewable energy sources which have shown the most rapid growth in installed capacity. There are of course renewable energy sources of heat and fuel, as well as of electricity. However, the present research focused on solar PV, and hence relates only to electricity supply.

The reasons for support to renewable energy sources may be grouped thematically in various ways. This section adopts the following groupings:

- environmental benefit including greenhouse gas emission reductions
- industrial and economic benefits
- correction or offsetting of market failures
- transformation of the electricity supply system, bringing with it energy security and import substitution
- other German government, EU and international policy grounds.

Naturally, there are interrelationships among these themes, that this review shall endeavour to identify.

There are two layers to the rationale for renewable energy support policies: the reasons for supporting renewables, and the (secondary) reasons for that support to take a particular form. Longer-term policy goals such as climate protection and electricity access for developing countries arguably require deployment of renewables on a massive scale. As a means to those ends, governments and the EU seek through support mechanisms to build up renewable energy installed capacity and drive down costs, through the "experience curve" process. That brings also in the interim benefits such as carbon dioxide emission reductions, import substitution, production, export and jobs.

3.4.2 German government and the EU

The most authoritative sources concerning the reasons for which the German government provides support to renewable energy are of course its own spokespersons and publications. The same applies to the European Union.

Jürgen Trittin, then the German federal environment minister (a Green), at the first preparatory meeting in June 2003 of the international steering committee for the Renewables 2004 conference in Bonn, said: "Renewables unify climate preservation, poverty reduction, technology development and the securing of jobs. And the setting of targets for an enhanced use of renewable energies is an important prerequisite for secure stable conditions for private sector investments." - quoted in Pecka (2004), who regards the deployment of renewables worldwide as "of critical importance" in improving access to energy by less developed countries. Mendonça (2007, p.37) observes that the SPD-Green coalition government emphasised ecological modernisation, climate change police, job creation and socio-economic development - with energy policy to be a leading example of all those.

The German government saw increasing its renewable energy industry's exports as a win-win, diffusing to less developed countries technologies which give them access to energy in a sustainable way, promoting local employment and reducing dependence on oil imports. See e.g. Wieczorek-Zeul (2004), who also makes the cogent point: "After all, we cannot deny countries such as India and China the right to development - we must only support them in making it a sustainable development.". Frau Wieczorek-Zeul, then and until 2009 federal minister for Economic Cooperation and Development, also refers to the importance of innovation in economies of the future, evidently seeing renewable energy technologies as an area of innovation suitable also for developing countries.
On the other hand, the European photovoltaics industry wants investment in R&D and manufacturing capacity "to keep this technology in Europe" and create jobs there (EPIA, 2004). The two positions are not necessarily incompatible, assuming EPIA's desire is to supply the European market from local production rather than by imports from eg the US and Japan. No doubt its members also want export markets ; but German companies at least are already well used to competition against local suppliers, and to moving production to e.g. China to cater for the local market.

Trittin (2004) observes that the exigencies of combatting climate change offer new models of industrial development - meaning that industrialising countries like China have the opportunity to build up renewable energy markets, production and employment. Trittin: "The boom in renewable energy in Germany is exemplary for newly industrialised countries in particular."

Trittin's successor Sigmar Gabriel, in his foreword to BMU (2006b), refers to energy security, employment creation, and helping less developed countries as reasons to support renewables. He also brings in an ethical point, that it would be unfair to burden our descendants with climate change. The rear cover of BMU

(2006b) carries a quotation from Germany's Basic Law, the Grundgesetz: "Mindful of its responsibility for future generations, the state shall protect the natural foundations of life....". Trittin (2004) made a similar reference, adding that "climate protection ensures global ecological justice".

BMU (2006) lists the following reasons for supporting renewables:

- climate protection
- security of energy supply
- prevention of conflicts over energy resources
- protection from fossil and nuclear energy cost increases
- easy decommissioning - no radioactive waste or mine spoil
- regional added value and employment
- electricity access for developing countries.

BMU (2004) states that CO_2 emission reductions through the use of renewable energy were 53 million tonnes (mt) in 2003, and the estimate for 2010 is 85 mt, half of that attributable to the functioning of the Renewable Energy Sources Act. The objective of the Act is that renewables make up at least 12.5% of German electricity supply by 2010, and 20% by 2020. (Germany passed the 2010 target several years early, and in early 2007 increased the target for 2020 to 27%.)

The then German President Horst Köhler identified the need to move away from fossil energy, to increase energy efficiency and reduce consumption, and to help less developed countries and especially Africa to avoid climate change damage (Köhler, 2007).

The highly significant meeting of the European Council on 8-9 March 2007 agreed on the key drivers for action on energy (listed overleaf) :

- climate change and the urgent need for carbon dioxide emission reductions - adopted a unilateral EU target of at least 20% cut (by reference to the 1990 level) by 2020;
- security of energy supply - although the Council seems to see that only in terms of continued access to fossil fuel imports;
- EU competitiveness - with special consideration for energy intensive industries, which risks running counter to efforts to reduce energy use and carbon dioxide emissions;
- the need to help developing countries achieve less energy and carbon intensive development.

Environment Commissioner Stavros Dimas saw EU promotion of renewable energy as for the first time explicitly linking climate change and energy policies (Dimas, 2007). The Council's conclusions were based on the EU Green Paper of March 2006 (EU Commission, 2006) on energy strategy. That identifies the reasons for action as being rising prices for fossil fuel ("high prices for oil and gas are probably here to stay"), import dependency, and climate change. The Green Paper is a somewhat curious mix. Parts suggest a mindset mired in the conventional energy supply system, with "energy security" apparently meaning better deals with suppliers like Russia, "diversification" procuring gas from more countries, and employment protection meaning "competitive" (i.e. subsidised?) energy for established industries. On the other hand, the paper also stresses the urgent need to reduce CO_2 emissions and hence for Europe to "act now, in particular on energy efficiency and renewable energy", recognising the positive effect also on job creation. It further acknowledges that renewables need support to develop against the present large scale centralised system. This is perhaps an example of committee drafting. European Commission (2005b) notes that renewable energy contributes to diversification and security of supply, by adding new capacity.

European Commission (2005a) compactly sets out, on p.13, the EU and international policy framework for support of renewables, including solar PV. The policy goals closely resemble those of the German government. It is unclear whether there is any significance in its listing energy diversity and security first, in view of the depletion of oil and gas resources, ahead of climate, energy access for developing countries, and European industrial benefits. This EU publication, however, despite its title offers only a rather restricted "vision". It is cautious, conservative and uncritical in its acceptance of resistance from vested interests in the present energy supply system.

Prof. Jochen Diechmann of the DIW economic research institute in Berlin has pointed out that Germany, in order to deliver its contribution to the EU's "20-20-20" target, namely 18% of final energy consumption in Germany from renewable sources, will need to achieve over 30% of electricity generation from renewables (Diechmann 2008). A 2004 report prepared by the European Environment Agency, an EU body, for the Renewables 2004 conference in Bonn explores in a little more depth the economic rationale for support to renewable energy sources (EEA, 2004). It notes their environmental, CO_2 emissions reduction and energy security benefits ; adding that renewables contribute to reducing price volatility. It also adduces "level playing field" arguments: renewable energy is an immature industry in need of support to enable its full development, and the cost of that support in the EU compares favourably with the subsidies other energy sources have received - for instance, in the USA nuclear received over 40 times the subsidy in its early developmental period that wind did in its (op.cit. p.16 Table 4). See also below about market failure as a ground for supporting renewable energy.

NGOs put forward similar reasons for providing support to renewables. For example, the German Engineering Federation refers to the environmental benefits, carbon dioxide emission savings, and security of energy supply (VDMA, 2005). Representatives of 35 countries at a renewable energy policy forum held in Mexico, 2006 noted as the key market drivers energy security, environmental benefits, and economic development including employment (IGREPF, 2006).

The order of listing of reasons for supporting renewables may imply differences in emphasis. On the other hand, that may be an illusion, since even a list numbered =1,=1,=1,=1 rather than 1,2,3,4 would still appear to have an order. Any differences are likely to be minor. Notwithstanding, there is commonality of views on which are the principal reasons to support renewables: climate change, industry and jobs, energy security, electricity access for less developed countries. That perception is reflected in the literature, with many researchers referring to the same cluster of main reasons. Haas (2001) identifies three of the main four reasons for providing support to renewable energy, omitting only help to developing countries: reduction in carbon dioxide emissions, employment creation (bringing also higher local tax and income revenues), and energy security through avoiding the risk of fossil fuel supply disruption and greater flexibility.

Raviv & Rosenstreich, 2006 adduce a similar set of advantages of investment in solar energy, albeit referring primarily to concentrating solar power rather than PV: lower cost over the medium/long term; energy security and import substitution bringing economic benefits, job creation, and increased competitiveness of EU industry; environmental benefits, not least through combatting climate change, and sustainability; taking a moral lead as an example to less developed countries. Some go further, identifying elements and dimensions of those broadly stated reasons, and in some cases further arguments for renewable energy development. Sawin (2004b) identifies the driver of German government action from 1990 to support renewable energy as "growing public concern about the safety of nuclear power, the security of energy supplies and the environmental impacts of energy use (incuding climate change)".

3.4.3 Climate change and CO_2 emission reductions

The threat of climate change as a reason to support PV and other renewables was starkly expressed by German MP Hans-Josef Fell at the 23rd European Photovoltaic Solar Energy Conference: "Only a total changeover to renewables coupled with energy saving will lead us out of the global crisis which threatens our very existence. We need worldwide feed-in laws and an end, finally, to the huge subsidies for fossil and nuclear energies." (quoted in Zervos, 2008). The Fraunhofer Society, Germany's main applied research body, believes that increased use of biomass, solar and wind energy "is the only way ... we can significantly and permanently reduce the output of carbon dioxide" (Fraunhofer, 2006).

Ekins (2004) identifies the market failure of carbon emissions "as a possible reason to support renewables". He anticipated Sir Nicholas Stern's famous description of climate change as "the greatest market failure in history" (Stern, 2006). Stern estimates the cost of emissions reductions, to stabilise atmospheric carbon dioxide at 550 ppm and avert catastrophic climate change, at an average of 1% of global GDP by 2050. That does not seem greatly out of line with premiums for an insurance policy against serious loss, such as for buildings. Koch (2002) indeed describes investment in renewables as "insurance" against climate change. The notion is not, however, new. Lovins & Lovins (1991) argued that transition to an energy supply system based on renewables and distributed generation would make sense in terms of economic and environmental benefits, whether or not it turned out that combatting climate change did in fact demand it: a "no regrets policy".

Also presaging Stern's conclusion was that of the German Advisory Council on Global Change (WBGU, 2003), that the cost of inaction would be much greater than that of transforming the energy system. Policy makers need also to heed the fundamental point made by former US Senator Gaylord Nelson: "The economy is a wholly owned subsidiary of the environment, not the other way round." (Nelson et al, 2002).

Sawyer (2008) makes another crucial point: that only rapid build-up of renewable energy coupled with improved energy efficiency can deliver greenhouse gas emissions reductions in the required timescale, namely such that total emissions peak by 2020, as needed to stabilise greenhouse gas levels in the 450-550 ppm CO_2equiv range according to the IPCC's 4th assessment report (see e.g. Sokona, 2009). Stern also concluded that the world needs low carbon technology on a large scale and rapidly (op cit, Part IV chapter 16, pp. 367-376). Gossling et al (2005) make the point that Germany has high per capita emissions of carbon dioxide emissions, a Kyoto protocol commitment to cut them by 21% relative to 1990, and a legally mandated phase-out of nuclear power stations, hence a pressing need to build up renewable energy capacity. Quaschning, 2003 on the other hand was rather dismissive of the contribution of renewable energy, including PV, to combatting climate change, arguing that rising emissions from e.g. air travel would cancel out the savings. Such a counsel of despair is reminiscent of the fossil fuel lobby's line. On the contrary, if certain emissions seem likely to rise, that would seem all the more reason to offset them by building up renewables.

According to analysis by Hennicke & Zylma (2004), "extra investment for renewable energy has the same economic effect as an energy tax but leads to immediate emission reductions", though it is not clear whether they envisage the tax being on use of energy regardless of source, or on e.g. carbon. (They also confuse the *cost* of an energy source, which should include externalities, with its *price*, referring to the "high cost" of renewables.)

3.4.4 Energy security

This sub-section includes substitution of fossil fuel imports, and recognition of the enormous potential of solar PV.

Koch (2002) concludes that renewables answer the challenge of how to combine economic growth with energy security and climate-friendly sustainable development, including access to electricity for less developed countries. By increasing diversity of supply, renewables also reduce risk, including of price volatility of fossil fuel imports. The International Energy Agency also identified energy security as grounds for supporting renewables (IEA, 2005). Security of energy supply could be threatened by political instability and uncertain integrity of local electricity networks in supplier regions, and by depletion of resources.

Jäger-Waldau (2007) points out that rising demand in developing countries is very likely to drive up fossil fuel prices, in the face of which threat the EU needs to reduce dependence on imports. Dincer (1999), among often broad brush and less than penetrating insights along the lines of pollution not being a good thing, makes a telling economic point: reducing imports of fossil fuels by developing indigenous renewable energy resources benefits the balance of payments, keeping the money at home.

Jackson & Oliver (2000) see the growth in the number and scale of government support programmes for PV as indicating confidence that in the long term it will achieve full competitiveness and large scale use. The Head Economist of Deutsche Bank, Norbert Walter, expounded a strategic view in 2005: "I feel that long-term energy security is more important than the short-term illusion of somewhat lower energy prices. Those who criticize renewables for allegedly being too expensive are just looking for a scapegoat." (quoted in Morris, 2008).

Greenpeace & EPIA (2006) speak of "the massive transformation and expansion that this sector [PV] will experience in the coming decades", predicting that once solar grade silicon supply and increased cell/module production capacity is in place - which industry commentators expected to be from 2009-10 (e.g. Cameron & Jones, 2006) - the PV industry "can become a serious player in the power sector". See Chapter 6 on the outlook for the next 5-10 years.

There have in recent years been several cases of higher than previously normal summer temperatures in Europe making river water too warm for use in cooling nuclear power stations, which as a result had to reduce output or shut down. See for instance Fell (2010a). Fortunately, at that time of year PV output is at its highest, and matches particularly well the midday peak of demand for air conditioning. This stands in ironic contrast to the frequent claim by the established energy industry that "intermittent" (more accurately, variable) renewables require backup from fossil or nuclear generating capacity.

No reference was found in the literature to a potential politico-military argument for reducing fossil fuel imports. If European countries reduce their dependency on oil and gas imports from Russia, that could have the side benefit, by reducing Russia's export income and future expectations thereof, of tempering Russia's view of its ability to compete in a new arms race, thereby helping reduce the risk of a new cold war. Hypothetically, of course ; but perhaps a little more worth considering in the light of Putin's decision in July 2007 to suspend provisions of the Conventional Forces in Europe treaty, and of the row about US plans to put elements of a missile defence system in eastern Europe.

The scale of savings through avoided fossil fuel imports depends on the price of oil, and that of natural gas which tends to track the oil price. One estimate is that a $20 rise in the price of a barrel of oil increases the total cost of Europe's gas imports by €15 billion annually (Kjaer 2007). The EU depends on imports for about 50% of its energy, predicted to rise to 70% in 2030 failing substitution by renewables and improvement in energy efficiency (Menna et al, 2007).
Oil prices have displayed considerably volatility, such as in 2008: from a high of $150 to low of $40 per barrel. The phenomenon of 'peak oil' means, however, that the price will inexorably rise as supply of easily extracted and therefore cheaper oil falls below demand. For background see for example the UK Energy Research Centre's detailed assessment (UKERC, 2009). The economic benefit of in-Europe energy provision from renewables will reflect that trend, both reducing the cost and keeping the money in the European economy instead of transferring it to oil and gas producer countries. It is therefore worth starting sooner to replace energy imports with jobs in the EU, even if it costs more in the short term (Morris 2008), instead of putting off action for the sake of preserving short-term profits. In 2007 Tony Juniper, then with Friends of the Earth UK, argued more broadly for beginning the decarbonisation process "while we still have the economic stablity and the money and the social comfort to do this without even noticing it" (quoted in Hopkins, 2008).

3.4.5 Employment creation, industry growth, exports

Hoffmann et al (2004) put it plainly: industrialised countries are not surprisingly trying to grab the biggest slice they can of the growing renewable energy industry cake. "The transition to more environmentally sustainable local economies would of course have huge job-creating potential. Examples include .... developing renewable energy sources on a substantial scale ...." (Hines, 2000).

Germany has a reputation as an environment conscious country, as the Green vote in federal elections of typically around 10% and experience of Greens in government exemplify. Its environmental concern is, however, "not just civilised and eco-friendly but hard-headed and businesslike too" (Booth 2008).

The then deputy Environment Minister, Astrid Klug, forecast in early 2009 (reported in Scheven, 2009) that employment in the renewable energy sector in Germany would reach 750,000 by 2020, and 900,000 by 2030. She also identified national pride as a further reason for supporting the growth of renewables: Germany did not want to lose its lead, rather remain ahead especially of the USA. Hirschl et al (2010) analyse in detail the contribution that renewables make to wealth creation in communities, finding that PV accounts for more than half of that effect, bringing benefits estimated at €5.8 bn in 2010.

Hillebrand et al (2006) reach a rather different conclusion. Their econometric model finds that while the build-up of renewables initially increases employment, a contractive effect of higher power costs offsets that and leads to a small net loss of jobs by 2010. They appear, however, to assume no further increase in fossil fuel prices, and not to factor in the costs of externalities nor of savings on electricity distribution costs. The unemployment level in Germany actually fell sharply in 2006-07, though the reasons were doubtless complex (including social system reforms and the confidence boost from hosting the FIFA World Cup™), and might have masked the predicted contractive effect, even while employment in the renewables sector continued to rise rapidly.

3.4.6 Other economic benefits

Hoffmann et al (2004) present a projection of solar PV support costs over the coming 40 years, assessing the total cost, net of value of electricity generated, at only €13bn. Considering employment and tax revenue benefits, they see those as fully offsetting support costs even without factoring in environmental gains. Hoffmann was at the time President of the European Photovoltaic Industry Association, but that need not call into question the analysis, which appears quite credible. After all, back in 1991 Lovins & Lovins argued that whatever the (then) uncertainties about climate change, transforming the electricity supply system to prevent possible damage made sense anyway in terms of the economic benefits, being as previously mentioned a "no regrets" policy (Lovins & Lovins, 1991). Jacobsson & Lauber (2006) likewise see renewably generated electricity as a reasonable choice in cost and investment terms.

A focus on "cheap" electricity, the cost per kWh including only generating cost and utility profits, is too narrow and reinforces the entrenched position of the existing supply system. A more sophisticated assessment of electricity prices, including especially externalities, environmental benefits and risk factors, is needed (Kammen & Pacca 2004). Munksgaard & Ramskov (2002) found that properly factoring in externalities would increase conventionally generated electricity prices by 40-50%, significantly improving the competitiveness of renewables including PV. Chien & Hu (2007) argue that increasing the share of renewables in electricity supply leads to higher "technical efficiency" in macroeconomic terms.

Analysis by the DWI institute (Deutsches Institut für Wirtschaftsforschung) in Berlin show that the build-up of renewable energy capacity in Germany has had a damping effect leading to lower electricity prices (Kemfert 2007). The Association for the Promotion of Solar Energy, SFV has published a series of articles explaining how the "Merit Order Effect" operates to reduce prices on the Leipzig electricity spot market, for example von Fabeck (2010a).

Apologists for the established electricity supply system often describe PV as "expensive" and call for more R&D to reduce its cost. To drive down the cost of PV, however, requires demand stimulation, leading to industry investment in production capacity at an increasing scale. R&D alone is not enough to reduce cost, as the former head of leading solar R&D institute Fraunhofer ISE in Freiburg reiterated in a magazine interview (Luther 2006a). Moreover, Prof. Luther stated in another interview (Luther 2006b) that the necessary build-up of PV production and of installed capacity does not require a technological breakthrough.

3.4.7 Need to transform energy system

Sigmar Gabriel, German federal environment minister up to 2009, took a strategic view: "Only those national economies which understand how to deal with energy in an intelligent way will be able to take a leading role in the global economy of the medium and long term." (foreword in BMU, 2006). Köhler (2007) sees a need for a "new industrial revolution" to change the energy supply system - which is also a major opportunity for German industry. He points out that the transformation need not mean giving up our way of life, and that the effects on our well-being and comfort will be much greater if we do <u>not</u> combat climate change. The Fraunhofer Society view is clear: "If we want to be assured of a reliable and affordable energy supply 50 years hence, now is the time to start making radical changes in the way we produce and consume energy (Fraunhofer, 2006). Jackson & Oliver (2000) argue that those who fail to perceive the sustainable future of the energy sytem and act early to secure their interests will end up the losers.

Government intervention to support the development of renewable energy technologies finds justification also in the need to counter the strong tendency to "technology lock-in" in favour of existing energy technologies, whose costs have had time to decrease, such as coal and gas fired electricity generation. As Trancik (2006) succinctly explains: ".... new and possibly better technologies cannot initially compete, even if they would ultimately achieve lower costs and better performance" (not least in carbon emission terms). Trancik also shows that energy technologies with a small modular scale, such as PV, are more responsive than those of larger scale to policy interventions, which are thereby more cost effective.

Mendonça (2007, p.3) identifies the principal barriers to faster deployment of renewable energy, which give rise to much of the extra cost of renewables and therefore justify incentives to offset the barriers, as:

- cost, administrative, technical, legal
- subsidies for fossil and nuclear energy
- investment decisions disregard fossil fuel price risks
- mismatch between the value of renewable electricity and its pricing
- project transaction costs per kW are higher for renewable energy

externalities of fossil and nuclear power are ignored.

Moreover, such technologies are inherently democratic. As Wieczorek-Zeul & Trittin (2004) pointed out, they make possible wider participation in decision making about energy options, including by involving smaller companies in technological innovation. The Association for the Promotion of Solar Energy (German acronym SFV) similarly argues that decentralising energy supply involves citizens directly in combatting climate change, and is thereby democratic (von Fabeck, 2008b). Greenpeace & EPIA (2006) believe that transition to large scale use of solar electricity will require changing our energy supply system from the present paradigm of centralised large generating units to a decentralised one, using distributed generation. They point out that such a shift would also mean "passing far greater control to individual consumers". BMU (2007a) likewise sees distributed generation as more democratic. An additional benefit of renewable energy promotion is that it "promotes centralised generation structures with significantly more public involvement ... and ... dismantles an unevenly distributed market power.".

Fuchs & Arentsen (2002) argue that governments "have a special responsibility to initiate a transition towards a sustainable electricity provision". They seem, however, to assume that the system will remain centralised, with consumers buying 'green electricity' from suppliers, and to overlook the contribution of individual household and local scale renewable generation.

Aitken (2003) points out that decentralised energy supply can greatly reduce risk of, and economic losses from, system failures. Examples of such failures include the major blackouts in the USA and Canada in August 2003, and in Italy in September 2003. Decentralised energy generating capacity is also too small to offer a terrorist target. A report by MIT's Engineering Systems Division (Jansson & Michelfelder, 2005), in addition to endorsing the economic and environmental benefits of renewable energy, identifies a benefit for electricity customers through the distributed nature of renewables making it possible to achieve higher reliability levels. Although their focus is the USA, they note that: "Significant involvement of policy makers in green power and utility regulation has created positive national economic impacts on countries like Denmark, Japan, the Netherlands and Germany.".

As for instance Gastal (2007) observes, the political decision in Germany to phase out all nuclear power stations gave a substantial impetus to development of renewables. Given the need to reduce carbon dioxide emissions, coal is not an attractive option for replacing all, if any, of the phased out generating capacity (*pace* CCS proponents, see 6.2.8). The existence of market failure and barriers to development of renewables provides further grounds for providing support. As Jäger-Waldau (2007) points out, the present conventional energy based system presents structural barriers to renewable energy adoption, which therefore needs initial investment - similar to that which fossil and nuclear energy received, mostly from public sources. So there is an argument of equitable treatment too. Sandén (2005) also cogently sets out the rationale for supporting PV, arguing that it involves lower cost than other approaches to reducing carbon emissions, such as a carbon tax. The robustness of the EU's 'ExternE' assessment of externalities was questioned before its final report (European Commission, 2003), for example in Krewitt (2002). VDMA (2005) agree that for fair competition one must factor in all external costs and benefits, such as environmental damage - or conversely renewable energy's contribution to environmental improvement as a public good. The UN Environment Programme's "Green Economy" study makes similar points (UNEP, 2011).

The last word on the topic of market failure arguably belongs to Lauber & Mez (2004), who remind us that "... the 'market' was and is actually invoked by the side [the established energy industry and its political supporters] which does not respect its basic principles of internalising externalities and a level playing field.". The International Energy Agency acknowledges (IEA, 2005) that "... the rationale behind most market mechanisms is that a level of support is necessary to build the capacity of the [renewable energy] industry to a point where such tariff or capital support is no longer necessary - the volume of products will drive the price down to a level that will result in a self sustaining industry.". That is also the goal of the solar PV industry.

Believers in market forces favour liberalisation of electricity markets as the way to arrive at the optimum supply system. However, Jegen & Wüstenhagen (2001) explain in their examination of Swiss energy policy that liberalisation by itself will not achieve environmental goals. The economically "first best" approach would be taxes reflecting externalities, but since taxes are unpopular and interest groups therefore oppose them and politicians avoid them, well designed subsidies for renewable energy are the next best approach in economics terms.

3.4.8 Phase-out of nuclear energy

For a comprehensive explanation by the then deputy federal Environment minister of why the SPD-Green government decided to phase out nuclear power, see Probst (2001). Prof. Dr. Lutz Mez of the Free University of Berlin takes a different perspective, arguing that the nuclear phase-out is in itself necessary in order to increase pressure to innovate in renewable energy (Mez 2008). The logic seems solid: with renewables as the only alternative to fossil fuels, Germany simply must deploy them rapidly. It thereby gains a strong position in the global renewable energy market, and avoids the many drawbacks of nuclear power (space prevents going into that issue - for a comprehensive exposition of nuclear problems see Lovins et al 2008).

3.4.9 Potential of PV

In the assessment of the German Advisory Council on Global Change (WBGU, 2004), only solar PV with hydrogen as energy carrier has unlimited potential relative to human energy demand, able to continue growing capacity after wind and other renewable energy sources reach their limits in about 2050. Jeremy Leggett, CEO of leading UK solar company Solar Century, also sees huge global potential for PV (Leggett, 2005), describing it as uniquely suited to the urban environment and "a key ally in the fight against climate change". Oliver & Jackson (2000) also noted the potential of PV, and observed that since the resource is available worldwide at a worthwhile level, support for PV was still justifiable in the case of countries in other than the sunniest regions.

3.4.10 Help to less developed countries

Increasing use of renewable energy in less developed countries benefits them by reducing dependency on imports of fossil fuel, and saving on the cost of those imports, which constitutes a considerable burden and diverts money from desirable alternative uses such as health and education; and can reduce cutting of trees for traditional biomass energy (Maithel 2008). WBGU (2003) identified health benefits from reduction of biomass fuel burning as a result of electrification using renewables - which moreover would become more affordable to less developed countries as market support mechanisms drove down their price. In statements to the 23rd European Photovoltaic Solar Energy Conference in Valencia, 2008, leading figures in the PV and renewable energy field adduced as a further reason to develop PV capacity the "moral obligation to help the poor", as World Renewable Energy Council chairman Wolfgang Palz put it (reported in Hand, 2008a). With more than 1.5 billion people lacking electricity supply, he suggested a target of using PV as "an ideal tool" to help 100 million of them by 2020, given PV's global availability.

As noted earlier, one benefit of building up renewable energy capacity is to reduce spending on imports of fossil fuels. Gartner (2009) put forward the view that such import reduction can also benefit human rights, for instance in oil producing countries in Africa, by reducing the flow of money to leaders who misuse the wealth to suppress human rights and hold on to power. It is, however, debatable to what extent this applies to PV, since oil accounts for a very small proportion of electricity generation: 3.1% in the EU in 2008 (Eurostat, 2011).

3.5 How? Reasons for choice of renewables support approach

The main debate has been about the relative merits of Quota and Feed-in tariff (FiT) based systems for supporting renewable energy sources. Issues include:

which most successfully leads to build-up of capacity, of still developing as well as more mature technologies ; at what relative cost ; whether "market conform" ; and the need for investor confidence. Those who favour a market-based approach (bear in mind Lauber & Mez's point in 3.4.7 above about market failure) argue for quota based systems. However, it seems to be widely accepted that a well designed feed-in tariff such as Germany's is markedly more successful in building capacity (Mendonça, 2007).

Kühn et al (1999) criticised the lack within support mechanisms of targets for installed capacity. However, capacity limits applied to FiT support in, for example, Italy led to a stop-go outcome, because the absence of commitment to support new capacity beyond the target damaged investor confidence. The cost limiting argument for setting a cap on added capacity eligible for support is besides open to challenge. The goals of carbon dioxide emission reduction, increased energy security and so on imply a need to achieve a high percentage of renewable energy, which in turn requires building a major industry to provide that capacity – that scaling up process drives down the cost of renewable energy systems. Germany is the prime example of how a well designed FIT can drive massive capacity build-up and cost reduction, at modest cost to electricity users (5-10% of the retail electricity price).

Kühn et al (op cit) and other advocates of quota based systems for supporting renewable energy, caps on support and green certificate trading, argue that they are in conformity with market economics, overlooking the less than triumphant achievements of conventional economic thinking in the last few years, described for example in Elliott & Atkinson (2008). Besides, Meyer (2003a) demonstrates how quota systems are not actually better than feed-in tariffs in terms of being market-based. Other considerations should therefore determine which system to use; and it is clear that feed-in tariffs are much more successful in promoting capacity build-up.

One must also distinguish between renewable energy sources which are commercial or nearly so, and those needing further development such as PV, for which a quota based system is not suitable. Moreover, as Lauber & Mez (2004, p.619) point out, fossil and nuclear energy do not conform to true market rules. They also note that a feed-in tariff system takes into account the externality costs of conventional electricity supply.

Martinot (2005) notes that the USA were the first to introduce a FiT, later discontinued. Germany among a few others followed in the early 1990s. By 2005 over fifty countries, states and provinces had adopted the FiT approach, over half of those since 2002. It is reasonable to conclude that they observed its success in Germany among others, and decided that it was the system most likely to deliver substantial build-up of renewable energy capacity. The European Commission concluded that "... well adapted feed-in tariff regimes are generally the most efficient and effective support schemes for promoting renewable energy", and that they "achieve great renewable energy penetration and do so at lower costs for the consumers" (EU Commission staff working document accompanying Directive on renewables, first part quoted in Smith 2008 and second in Hinrichs-Rahlwes 2008).

Morris (2007) sets out succinctly the advantages of FiT over Quota based systems, in particular that the German FiT "unleashed the collective might of small investors", avoided picking winners among renewable energy technologies (which Quota systems in effect do, by favouring the currently lowest cost ones), has driven cost reductions, and despite opponents' claims that Quota systems are superior because market based, in fact "FiTs hand everything over to the market" as people decide on the basis of prices and return on investment whether for example to install a PV array.

Co-architect of the German renewables support mechanism Dr Hermann Scheer wrote in his Foreword to Mendonça (2007) that: "Our task is to transform the macro social economics [of centralised large scale energy supply] into the micro incentives that will mobilize renewable energy technologies. .... feed-in legislation has been proved to be the most effective policy for this purpose.". Mendonça (op cit, p.14) analyses the pros and cons of Quota systems and reaches the rather damning conclusion that ".... the reality is that the [quota] system is in general significantly less cost-effective than the FiT system, and is flawed and inequitable in a number of ways.". He also points out (op cit, p.42) that opponents' attempts to press for "harmonisation" - on a tradeable certificate, quota model - are *not* well founded in EU law. Legal opinion states the contrary; and the majority of member States chose FiT - so any harmonisation should be on FiT, not Quota.

Arguments against the UK's 'Renewables Obligation' (RO) Quota based system from the economist's perspective are set out in, for example, Johnston et al (2008). They assess that the RO "struggles to deliver on deployment effectiveness, cost efficiency and technological diversity". Further evidence that FiT is more cost effective than Quota systems is that the cost to consumers per kWh of renewable energy support programmes turned out to be lower under a FiT (Ernst & Young, 2008), as has the support cost per kWp of capacity installed (Toke, 2004). Mitchell et al (2006) concluded that a FiT greatly reduces investor risk, thus promoting more investment than a quota system like the UK's Renewables Obligation (RO). The lack of certainty about the future price of RO Certificates increases the risk to investors, hence the cost of capital. The German FiT system by contrast "created a secure investment climate" (Elliott, 2008). Elliott describes the UK RO as "an ineffective, inefficient and costly approach". To attain EU renewable energy targets and beyond will require developing and therefore supporting a wide range of technologies: "it's a matter of silver buckshot, not a silver bullet" (Jones 2008).

As regards capacity building, the key difference between a feed-in tariff (FIT) and a quota based system is that a FIT sets *prices*, thus providing an incentive to increase generating capacity in order to maximise income ; whereas a quota system sets the *capacity* which qualifies for payments, giving no incentive to exceed it. It follows that quota systems favour the currently lowest cost renewable energy technologies, as the cheapest way to achieve the capacity that the quota requires. Far from being 'technology blind', as mentioned above they in effect 'pick winners'.

The European Photovoltaic Industry Association published in January 2008 a detailed analysis of the merits of feed-in tariff schemes, by contrast in particular with quota systems but also with other approaches such as grant support and Kyoto mechanisms (EPIA 2008). Held et al (2007) also set out the many positive properties of FiTs. It is important that a feed-in tariff be paid over a long enough period to cover the cost of the renewable energy system in question, since that is closely related to the initial up-front investment, which is obviously not going to reduce if system prices subsequently fall. A taper or 'degression' provision in the FIT regime reflects that price reduction, and the expectation that after a certain number of years the investment will become viable without any FIT support. The guarantee of FIT receipts for such a period (20 years in the German scheme) makes the cost vs payback calculation straightforward, so provides confidence to the investor - and, importantly, to banks which are willing routinely to finance investment in renewables including private household PV systems.

A feed-in tariff scheme is simpler, less bureaucratic and with lower administration cost, and thus more accessible to small private investors, including householders. As Galán (2004) points out, since FiT income depends on the output of e.g. a PV array, it provides a clear incentive to the owner to install the most efficient modules and optimise performance and output, thus delivering more electricity and carbon dioxide emissions reduction. A FiT scheme also gives incentives to PV producers to innovate and reduce costs (Menanteau et al, 2003), such that they can either earn a higher margin, or be able to continue selling by reducing prices in line with annual degression in the FiT rate, or a combination of the two.

Bernow et al (1998) point out a further advantage of the FiT approach: it facilitates earlier deployment of pollution reducing renewable energy systems into the areas which need them, instead of only into a limited number of 'lowest cost' areas as a Quota system encourages.

For an assessment of the pros and cons of a less well designed feed-in tariff system, that of Spain, see del Río & Gual (2007).

3.6 Experience curve - cost reduction - affordability

Although not explicitly identified by Rogers (2003), the cost of an item is self-evidently a factor in decisions about whether to purchase it, whether it be e.g. an energy saving lamp or a solar PV system. How demand for PV interacts with its cost is a central theme of the research presented in this thesis. As explained in the Introductory chapter, the research explores the hypothesis that the feasibility of financing a system is more important to persons considering installation of PV than is profitability. However, reductions in the cost of PV are clearly relevant in that context too, as they are in relation to the postulated "desire push-incentive pull" spectrum and the location along it of the "decide to buy" threshold (see Figure 3 in Chapter 1 section 4).

What does "the cost of PV" mean here? One sense of the phrase is of course the price that someone pays to have a system installed on the roof, factoring in any financing costs, insurance and other elements. Normally more meaningful to a potential purchaser, however, is the overall financial picture taking into account expected feed-in tariff income. That relates to such elements as projected return on investment, payback time, amount of own capital employed, and the prospect of effectively free electricity after amortisation of the PV system. Sub-section 3.2.2 above dealt with return on investment. 3.7.3 below will consider consumer psychology in relation to purchasing decisions.

The principal element of the price of a PV system is that of the modules and inverter. As has been observed in the case of other electronic goods such as digital cameras, the key driver of reduction in PV cost has been scaling up of production. The relationship between the two is customarily referred to as the "experience curve" or "learning curve". For a succinct explanation of the concept, see Berglund & Söderholm (2006). Neij (1997) described the "experience" involved as "a long-term development process which represents the combined effect of a large number of parameters, which may fluctuate on a short time-scale"; and which does not *per se* cause cost reductions, rather provides opportunities for them. Resch et al (2004) found it "a proper tool for strategic decisions" on support for renewable energy.

According to Sagar & van der Zwaan (2006), technological change has only two components: R&D, and "learning by doing". The learning rate is highest in the initial deployment phase, and produces improvements which aid large scale deployment. Thus deployment is needed in order to gain experience, and incentives are needed to achieve that deployment. Grübler et al (1999) argued that investment in intervention is needed to increase the chance that markets will select the needed technologies, which may sound like "picking winners" but in practice is about giving all technologies the chance to grow. They found that "new technologies can penetrate the market even if they are initially a factor of

40 (or more) more expensive than the existing dominant technology.". Berglund & Söderholm (2006) likewise note that early investment in new technologies is needed to obtain economic benefits, including later cost reduction.

Sagar & van der Zwaan (2006) argue that since experience curves do not explain *why* cost reduces, there is no guarantee that they can safely be extrapolated. Nemet (2006) also questions the standard experience curve model, though finds that the considerable increase in PV manufacturing plant size is "the dominant driver of the change in cost".

On the other hand, van der Zwaan & Rabl (2003) considered there to be "ample reason to assume that experience curves [for PV] based on learning parameters so far provide an appropriate means to assess their future cost reductions". The curve for PV has been broadly consistent for decades, as shown in EPIA & PVTP (2010): since 1979 a good fit to a straight line, of 22% price reduction for each doubling of cumulative sales. Koch (2002) puts the reduction at "roughly 20%", adding that it is observed to hold good over three orders of magnitude from 0.5-1000 MWp. The analysis by McDonald & Schrattenholzer (2001) also supports a learning rate for PV of about 20%. Parente et al (2002) put it at 20.2% up to 1990, accelerating to 22.6% from then to 2000 - during which period a series of incentive programmes were launched. On the other hand, a line of best fit can obviously pass between data points to either side of it. Poponi (2003) found a mixed pattern from 1976-2002, with PV prices in some periods reducing and in others remaining stable or increasing - as indeed they did in 2005-07 in response to a supply shortage of solar grade silicon, as described in, for example, Flynn & Bradford (2006) and Bernreuter (2006). That suggests that a somewhat longer term (say 5 year) projection of prices is less risky than a shorter term one, rather as in the case of the stock market.

Neij (1997) points out that renewable energy technologies, being small in scale and modular, are more similar to mass production than to conventional power plants. Andersson & Jacobsson (2000) observed that an experience curve with a 20% price reduction is not out of line with that seen in the electronics industry, also silicon based and akin to PV. They set out the concept of a "bridging market", such as a rooftop programme, arguing that a set of such markets of increasing size needs to be exploited to foster development towards low cost PV, eventually self sustaining in development and diffusion. That closely resembles the concept of "strategic niches", as described for example by Shum & Watanabe (2007), in which PV growth occurs more rapidly in, still sizeable, niche applications where it has the edge over conventional energy technologies. Earlier, van der Zwaan & Rabl (2003) saw "promotion of PV in a variety of useful niche markets [as] essential for its required cost reduction and ride down the experience curve".

Sandén (2005) calculated that a learning rate (or "progress ratio") of 20% for PV would involve support costs adding a maximum of US¢0.1 per kWh to electricity bills, to achieve PV electricity cost competitive with coal-fired generation by 2021 in OECD countries. Schaeffler & de Moor (2004) found that PV cost reduction was on track to achieve competitiveness with fossil and nuclear generated electricity, but would need both market growth and learning rate of ≥20% to reach that goal. Breyer et al (2010) present updated analysis of PV experience curve and R&D expenditure, concluding that PV market diffusion will be evolutionary and rapid, achieving energy security at much lower R&D cost than nuclear power.

Luque (2001) analyses the "learning curve" concept in combination with that of demand elasticity; but does not examine a distributed generation paradigm, nor is it clear whether the effect of FiT support on effective price is taken into account.

3.7 Socio-psychological aspects of adoption of PV

3.7.1 Environment consciousness

Gastal (2007) saw German people's concerns over environmental issues as a trigger for early action to develop renewable energy. That is borne out by the history, detailed in section 3.3 above.

George Monbiot argues, primarily but not only in a UK context, that governments will not run the political risk of taking measures against climate change if they would impact upon voters' lifestyles: "Governments have no interest in challenging our illusions. If their aspirations and our aspirations diverge too widely, the will lose elections. They won't take real action until we show them that we have changed." (Monbiot, 2007, p. xvii). That rather cynical view applies, however, to a significantly lesser extent in Germany. The environmental consciousness of the electorate is high, the Green vote historically in the 7-11% range but over 20% in late 2010 opinion polls, and of course the country has experience of the SDP-Green coalition government of 1998-2005. That background suggests that in Germany the government has more scope to pursue environment- and climate-friendly policies without fear of political suicide and electoral defeat.

On the other hand, the German government has on occasions shown itself to be distinctly ambivalent on environmental issues, for example in handing emissions permits free to electricity companies, in opposing EU plans to reduce car CO_2 emissions per kilometre, in its 2008 demands for free emission permits for energy intensive industries (Kirschbaum, 2008a), and most recently in extending nuclear plant operating lifetimes (see 6.1).

3.7.2 forsa surveys

The Gesellschaft für Sozialforschung und statistische Analyse (Social Research and Statistical Analysis company), known as 'forsa', has carried out annual nationwide surveys of attitudes in Germany to renewable energy. They provide a wealth of information, segregated by region, gender, age band, educational level and political affiliation. A full examination and analysis of the results is beyond the scope of this review; following are selected responses at the aggregated 'all Germany' level, from the 2009 survey (forsa, 2009a). They show attitudes strongly supportive of renewable energy, including among voters for the right of centre "business friendly" parties.

95% of respondents rated the use and build-up of renewable energy as "extremely important" (40%), "very important" (40%) or "important" (15%). The highest combined percentages for 'extremely/very important' were seen among Green voters (91%) and people aged 30-44 (86%); the lowest among FDP voters (74%) and CDU/CSU voters (79%), 14-29 year olds (69%), and in the south of Germany (78%). It is noteworthy that the difference between 'highest' and 'lowest' scores is not great, and the 'lowest' scores are still clear majorities.

The overall combined percentage for 'extremely/very important' of 80% is almost identical to the 81% of respondents who supported substantial investment now in renewables, and reduction in fossil and nuclear energy use. Both Green and Die Linke (left wing socialist) voters were 95% in favour of that; but so were 76% even of CDU/CSU voters, and 66% of FDP. Overall 75% of respondents were 'totally' or 'strongly' for 100% renewable electricity supply in the medium to long term; 73% of CDU/CSU and 66% of FDP voters wanted that. Interestingly, only 47% overall rated it 'definitely' or 'probably' feasible, as did a surprisingly low 54% of Green voters, Die Linke supporters being more positive on 63%.

On the issue of external costs (not reflected in electricity prices) of fossil and nuclear energy, 91% of respondents agreed that the government should calculate and publish them; 88% that they should be shown on utility bills; and a solid majority of 77% that energy companies should bear the cost of externalities, not the State.

Of particular note in relation to subsequent developments (see Chapter 6) are the survey results concerning support for renewables. 76% of respondents overall were in favour of maintaining support at its (then) present level. That was the wish of 86% of Die Linke, 85% of Green, 73% of CDU/CSU and 71% of FDP voters. The published survey report does not, however, give disaggregated figures for solar PV and other renewables. Accordingly, it is unclear from this survey whether there is equal support for feed-in tariff incentives for PV, the cost of which to electricity users has been increasing, in comparison with other renewables. However, survey findings published in October 2010 (BSW, 2010) showed 75% of Germans willing to meet the cost of PV support, up to €¢2 per kWh, which is less than the PV FiT cost then forecast for 2011. That level of support was consistent across geographical, age and educational categories.

3.7.3 Other surveys

Kuckartz & Rheingans-Heintze (2006) report extensively the findings of a series of surveys in Germany from 1996 to 2004 on the topic of environment consciousness. The questions were the same in each survey, permitting comparison over time. That shows that environment consciousness in Germany has remained high, and even slightly increased. The number of survey respondents who identified 'environment protection' as the most serious problem facing Germany increased in the 2004 survey, for the first time in seven years, and has not since fallen. It was in third place - in a free answer, not selection from a list of options - at 18%, after 'labour market' on 55% and 'economic situation' on 20%.

When asked to rate the importance of specified issues, on a four point Likert scale, 92% rated environment protection as "very important" (45%) or "quite important" (47%). However, the "very important" percentage is only in eighth place among issues, behind health, education, crime and others. Young adults, aged 18-24, rated the environment as *less* important than did older age groups; but that was the case with the other issues too, except for education. A notably high importance rating was given to intergenerational equity: 51% "very important", 37% "quite important", and 10% "somewhat important".

Comparing the results of the 2004 survey with earlier ones:

- awareness of environmental crisis was 4% higher
- no increase in the percentage downplaying the problem, regarding it as exaggerated, or supporting "techno fix" solutions
- significant increase in awareness about sustainability

The results of a special EU-wide survey, Eurobarometer (2008), place Germany above the EU average - though not in the top group - with respect to a number of indicators of environment consciousness in relation to climate change and energy. Table 2 overleaf sets out the figures for a selection of those indicators, comparing the average of the 27 EU members, Germany, and the UK.

Particularly interesting are the German responses to statements 3.2 and 3.2 together with 6. A higher percentage of respondents than the EU average felt a duty to act for the environment, and a higher percentage felt that citizens were doing enough (lower percentage dissatisfied with citizens' efforts). That could reflect a tendency to give the "right" answers; but one would expect any such bias to apply across the range of countries and respondents, leaving relativities essentially unaffected. It could be a sign of a certain smugness on the part of Germans. If so, they have arguably earned it, given their track record on promoting renewable energy, albeit offset to an extent by support for coal fired electricity generation and for the motor industry.

	(percentage agreeing with statements; numbering arbitrary, not that in the survey)	**EU avge**	**Germany**	**UK**
1	climate change is a serious problem	62	71	57
2	*dis*agree that CO2 emissions have only a marginal effect on climate change	55	62	41
3.1	corporations are not doing enough to help combat climate change	76	75	70
3.2	citizens are not doing enough	67	54	60
3.3	our government is not doing enough	64	48	54
3.4	the EU is not doing enough	54	53	49
4.1	EU renewable energy target (20% of electricity by 2020) is too ambitious	13	14	20
4.2	the EU target is too modest	22	28	18
4.3	the EU target is about right	47	48	44
5	we have installed renewable energy at home	5	7	5
6	citizens have a duty to protect the environment	61	69	52

Table 2 : indicators of environment consciousness level ; source = Eurobarometer (2008)

The relatively high sense of citizen duty to protect the environment (6 in Table 2 above) fits with the view (3.1) that corporations are not doing enough to combat climate change. As Eikeland (1998) commented, in a liberalised electricity market the primary concerns of electricity corporations are competition and short term profit, so building up renewable energy is not a priority. Accordingly, if citizens want it to happen they must do it themselves.

That is, however, not entirely consistent with survey findings reported in Kuckartz & Rheingans-Heintze (2006, p.24). Only 40% of German respondents agreed that environment protection begins with individual behaviour, 29% thought it difficult for individuals to make a substantial difference, while a substantial 33% were undecided. The percentage endorsing individual responsibility was only a little above the EU average; it was markedly higher in Sweden and Finland. Kuckartz & Rheingans-Heintze (op cit, p.33) also point out a generic problem with surveys of environmental behaviour: the tendency to attract more "correct" responses than would accurately reflect people's actual conduct, because they want to look better by giving the "right" answers.

They also, however, report from surveys in 2002 and 2004 some indicators of a higher level of environment consciousness: age range 25-59, higher level of education, female gender, resident in larger cities (over 500,000 population) and western Länder, religious adherence. Women aged 25-49 of higher educational level display on average the highest environmental responsibility of all Germans. Income level on the other hand is a poor indicator. Further evidence of the generally high environment consciousness in Germany is in findings of their 2002 survey: 72% of households had even then installed at least one energy saving lamp, 42% reported never leaving devices in standby mode, and 82% declared themselves willing to spend more to get a more energy efficient appliance - provided that the electricity savings would repay the cost in five years.

A high profile yardstick of environmental concern among the German people is of course the level of voter support for the Greens (Bündnis 90/Die Grünen). Although their policies cover the full range of issues, including for instance social justice and peace, they are often referred to as "the environmentalist party" (e.g. in Kirschbaum, 2010). From 1998-2005 they were in coalition government with the SPD, during which period laws to promote renewable energy (EEG 2000 and 2004) and to phase out nuclear power were enacted. Historically the Greens polled in the 7-11% range in federal elections; 10.7% in that of September 2009. As Kirschbaum (2010) reports, they reached an unprecedented 24% in opinion polls in September 2010, interpreted as a reaction to the CDU/CSU and FDP government's plan to extend nuclear power plant operating lifetimes. Land elections will take place in March 2011 in both Baden-Württemberg and Berlin. Latest opinion polls in Baden-Württemberg, on 20 March 2011, put the Greens and SPD just ahead of CDU+FDP.

In the regional (Land) parliament election in Germany's most populous region Nordrhein-Westfalen (NRW) in May 2010, the Greens won 12.7% of the seats - almost double their result in 2005, 6.4%. Among the key election issues which commentators, such as Ehrenstein (2010), identifed as contributing to that success was the future energy supply system. A coalition of SPD and Greens took over power in NRW from the CDU, an outcome which also cost Chancellor Merkel her majority in the upper house (Bundesrat) of the German federal parliament. Beuermann & Santarius (2006) note that successive opinion polls in Germany have found a high level of concern about environmental protection, as well as about unemployment, the two coming together in support for taxes on energy designed to reduce both environmental damage and employment costs. Booth (2008) called Germany "a society humanely and intelligently engaged with the 21st century".

Diamantopolous et al (2003) warn that pro-environment attitudes are not necessarily reliable predictors of 'green' knowledge or behaviour. They point for example to studies showing younger people as apparently more environmentally concerned, but older people as in practice acting more greenly, perhaps because of a difference in financial means, against a background of widespread acceptance of environmental responsibility as the social norm in Western culture.

3.7.4 Take-up of 'green power' electricity tariffs

Does the take-up in Germany of 'green power' electricity tariffs, which promise to support a higher proportion of renewably generated electricity, shed any significant light on the level of environment consciousness in Germany as a possible driver of the growth of PV ?

3.7.4.1 A slow start

Electricity suppliers have offered 'green power' tariff options since the late 1990s. With the exceptions of the Netherlands and Sweden, take-up of such tariffs was very low, in the 1-2% range, until around 2005. That is comparable to the "pioneers" category, the first 2.5% of innovation adopters, in Rogers' theory of diffusion of innovations (Rogers, 2003); which is plausible as such a 'green power' tariff is a form of innovation. On that view, it was perhaps to be expected that take-up would increase after a few years of experience (see below).

The literature explores possible reasons for the initially low take-up. Wiser (1998) identifies as an obstacle the economic incentive for people to "free-ride", that is share in the benefits of a public good such as increasing renewable electricity generation capacity without contributing to the cost of it, instead pursuing their own advantage in the form of lowest available electricity tariff. Views differ on whether indirect contribution such as through taxes constitutes conscious willingness to pay (WTP). Wiser notes that actual participation in 'green power' schemes was much lower than expressed WTP should imply; observed also by Zarnikau (2003), and Diaz-Rainey & Ashton (2008) in the UK. Wiser also points out, however, that one solution to the "free-rider" problem is a mandatory collective programme of support for renewable energy. He wrote before the German government introduced its first feed-in tariff in 2000, which is just such a programme.

Fouquet (1998) argues in the case of the UK that information, and the ability to understand it, are important drivers of 'green' purchasing decisions, citing the finding by Bergstrom et al (1990) that WTP increases with people's awareness of the environmental issues. For a discussion of disclosure to consumers of the sources of electricity supplied to them, see Markard & Holt (2003). Zarnikau (op cit) suggests that WTP increases with income and educational level.

Wiser (1998) concludes that people do not act solely out of self-interest, but contribute more to public goods than traditional economic theory would predict; and describes four approaches to increasing demand for 'green power' schemes. Menges (2003) applies contingent valuation theory to conclude that "individuals do not treat political measures [such as a feed-in tariff] as substitutes for their private activities", in which "impure altruism" gives them a subjective personal benefit from paying a 'green power' tariff.

Yet despite surveys indicating that large numbers value environment friendly products, take-up of 'green power' has in practice been low. Wiser et al (2005) found median participation of just 1% of US residential customers in 'green power' schemes at end of 2002, with a range from 0.1-6.5%, the more successful schemes being those which had been operating for longer. One US study of the motivations of actual participants in such a scheme (Clark et al, 2003) found the top three to be concern for the environment, altruistic concern for other local residents, and own health interests.

The then federal environment minister put take-up in Germany in 2005 at 1-2% (Trittin, 2005). A Eurobarometer special survey for the European Commission conducted in 2005 found that 56% of Germans would not be prepared to pay any more for 'green' electricity (Eurobarometer, 2006); though a relatively high 29% stated themselves willing to pay up to 5% more, and 12% of respondents up to 10% more (the combined total of 41% was identical to that in the UK). WTP seems to have decreased since 2002, when a survey (Datamonitor, 2002) found between 31-45%, depending on age band, unwilling to pay any premium; 38-57% ready to pay up to 6% more; and 23-35% up to 10% more. Kuckartz & Rheingans-Heintze

(2006) report from their 2002 survey that only 9% of respondents intended to sign up to a 'green' tariff, 38% would consider it, but 50% definitely ruled it out. The main reasons were lack of information - interestingly, across all demographic categories; and a perception of high cost, especially among those with lower educational level and income.

It might be that there is an interaction between WTP for 'green electricity' and feed-in tariff levels - the 2002 survey was after introduction of Germany's first FiT, the 2006 survey after the increase in FiT levels in 2004. To the extent that people feel they are already through the FiT paying a (collective) premium to support renewably generated electricity, they may be less willing to pay a second premium for 'green power'. Komor (2004) identifies as reasons for the low take-up of 'green power' tariffs in the UK the requirement, through the Renewables Obligation, that electricity suppliers in any case steadily increase the renewable proportion in the supply mix; and that market liberalisation was sold to consumers as bringing lower bills, which meant that a premium price for 'green' electricity lacked appeal.

General concern about the environment does not necessarily translate into specific behaviour, such as buying 'green' electricity (Bamberg, 2003). A significant factor may be a tendency of electricity consumers to go with the 'default' supply option presented to them (Pichert & Katsikopolous, 2008), which often is the conventional fossil and nuclear dominated mix rather than 'green' electricity.

3.7.4.2 Brighter spots

Is there anything different about the places where 'green power' take-up was from an early stage higher? Komor (2004) lists four main reasons for the high take-up in the Netherlands, 26% by 2003: marketing, including endorsement by the World

Wide Fund; government policy of supporting renewable energy; permitting supplier switching only to a 'green' scheme; and equal pricing of 'green' and standard electricity. The last factor seems very significant, as it removes the WTP dimension, requiring only the effort to switch supplier rather than a financial sacrifice.

Middtun & Koefoed (2003) note that the green labelling scheme in Sweden achieved notable growth, accounting for 7% of electricity sold in 2000, reasons being its inclusion in the respected "good environmental choice" certification system, broad participation by the electricity industry, and - here again - low price, thanks to inclusion of abundant hydroelectric power as 'green'. Ek & Söderholm (2006) on the other hand describe take-up as "modest", and attribute that largely to perceptions that buying 'green power' would not achieve results, and that improving the energy system is others' responsbility.

Komor (2004) reported involvement in community affairs as a good predictor of 'green' electricity purchasing. That may chime with the action of local initiatives as a driver of demand for PV: see 3.8 below.

3.7.4.3 Germany

Detailed surveys by Arkesteijn & Oerlemans (2005) concluded that in the Netherland "early adopters of green electricity are persons who are knowledgeable about the use and background of sustainable energy and who often take a positive position on environmental and related issues". In that case, why was there not higher early take-up in Germany where the Green vote has been in the 7-11% range? Perhaps it is simply a matter of inertia, a tendency of electricity customers to stick with a supplier rather than switch, as described in Pichert & Schwarzburger (2007).

Another possible reason is that Germany has such effective feed-in tariff support for renewably generated electricity and, as Markard & Truffer (2006) suggest, that makes green power schemes largely irrelevant. That implies that people who favour renewable energy feel that they are already contributing their share, whether by generating from a PV array on their roof or participation in a communal array (or wind turbine), or by helping to fund the increasing share of renewables in electricity generation as a whole, 16.1% as at the end of 2009 (BMU 2010b). Psychologically they may equate the feed-in tariff element in their electricity bill to, in effect, a 'green' premium on their tariff; in which case they may well be less willing to pay a further premium in order to support 'green' electricity.

Surveys in Germany, most recently forsa (2009a), show a high percentage in favour of support for renewables, which in practice means the feed-in tariff. No reports have been seen of protests by electricity consumers against the level of the PV FiT or the cost of it to them - only by organisations purporting to speak on behalf of consumers, which might however have other agendas. (Of course, lack of objection is not the same as positive acceptance; but that does not entitle one to assume that there is unexpressed opposition.) Arguably this amounts to willingness to pay a small premium for 'green power', on a collective basis; especially by those who are not personally benefitting from FiT income by having e.g. a PV system on their roof.

In which case, who are the people nonetheless buying 'green' power? They may include those who would like to generate their own, but cannot - such as students, tenants, or householders with no suitable roof space for a PV array, who do not have the option of buying a share in a communal system. Gossling et al (2005) found students in Freiburg, Germany very positive towards 'green power' but difficult to reach in marketing such tariffs.

There may be residual demand for a 'green' tariff by people who want to be sure that the power they use, over and above what their own microgeneration system (or their share of a communal one) produces, is from renewable sources. Even though it is rarely possible for a supplier to guarantee that: usually the 'green' tariff premium goes to support existing or in some cases new renewables capacity, but the electricity transmitted to the subscriber's home is the standard mix including fossil and nuclear generated power. There would seem to be scope for further research into this question.

In some cases the 'green' tariff premium goes directly to support local renewable energy capacity. An example is the city of Freiburg im Breisgau in southwestern Germany, well known for its support for renewable energy, which hosts among other related organisations the Fraunhofer Institute for Solar Energy Systems. Some customers of the regional power company Badenova, which is jointly owned by several municipalities and a natural gas company, choose to pay a small premium on their electricity tariff to support PV, biomass and small hydroelectric power, including through a €300 subsidy for PV installation (PEI, 2010a).

However, Batley et al (2001) in the UK case, and Rader & Short (1998) in the USA, found that the limited take-up of 'green power' tariffs led to very little if any installation of new renewable generating capacity. The offer varies, but in most cases suppliers offering a 'green' tariff do not own the generators, rather buy in the electricity from capacity installed for instance to meet a quota or to earn feed-in tariff income. A current exception is Ecotricity in the UK, which owns wind turbines and pledges to invest its profits from 'green' tariffs in new capacity.

3.7.4.4 Recent growth

The Renewable Energy Policy Network REN21 report a significant increase in the last few years in 'green power' take-up (REN21, 2010). The number of customers on such tariffs exceeds 6 million in total, most of them in Europe and the USA, plus Australia, Japan and Canada. However, that still represents under 5% of the market: as it were, into the "early adopters" phase according to Rogers (2003). The REN21 report names Germany as 'green power' leader in Europe, having overtaken the Netherlands. Residential customers in 2008 were estimated at 2.2 million, treble the 2006 level of 750,000.

3.7.4.5 Conclusions

Germany's leading position as regards 'green power' take-up in Europe is further evidence of the environment consciousness of its people. However, no information appears to be available on the degree of overlap, if any, between the 2.2 million (as at 2008) 'green power' customers in Germany and the approximately 560,000 households which have PV installed on their roofs (see 6.3.4). Nor was anything found in the literature relating willingness to pay for 'green power' to readiness to install PV. It is accordingly not clear whether one can say more than that the level of environment consciousness of the population in Germany provides fertile soil, in which the possibility of acquiring one's own 'green electricity' generation capacity can germinate and grow.

3.7.5 Consumer psychology: environmentally responsible behaviour

This sub-section addresses the questions: what indications are there in the literature of the profile of a person who desires to install PV, and of the drivers of that desire? and, to what extent are that profile and those drivers applicable to people in Germany?

3.7.5.1 Survey findings

A multi-country poll in 2007 for the BBC World Service (BBC, 2007) found high levels of acceptance that combatting climate change will require changes in behaviour and lifestyle, price increases for high carbon fuels, and energy taxes. The proposition of devoting the additional tax revenues to promoting energy efficiency and renewables found even higher acceptance. In Germany, 87% agreed on the need to modify behaviour, the same percentage as in the UK. 59% of Germans (54% of Britons) agreed with raising energy taxes. 70% of Germans agreed with higher prices for high carbon fuels, especially coal and oil ; 77% in the UK. (When car fuel and energy costs did rise in the UK in 2007 and 2008, there was widespread discontent, possibly because economic pressures reduced disposable incomes and willingness to translate attitude into action.)

There is some contrast with results reported by Dunlap et al (1993), when Germany was by no means consistently leader among industrialised countries. It took first place on perception of environmental problems as a serious issue, with 67%; but only 63% (9th place) of Germans felt personally concerned. 73% (2nd place) put environmental protection ahead of economic growth; but Germany placed 10th (59%) on willingness to pay higher prices to protect the environment. Another contrast was between the proportion of respondents who agreed that citizens should take primary responsibility for environmental protection (25%, 4th place), and the mere 13% (11th place) who believed that individuals and citizen groups could have a substantial influence.

A survey in the USA in 2007 by RBC Capital Markets (RBC, 2007) found 87% support for early government action to promote renewable energy, by subsidies and incentives. 60% said that they would accept a solar power plant in their town. Other US surveys indicate that concern about climate change is not a strong motivator to adopt 'green' power (Lacey, 2008), more effective motivators being desire for energy independence, security and price stability.

3.7.5.2 Profile of 'green' consumers

Research into what drives 'green' behaviour and purchasing decisions has produced a diverse range of findings. It is, moreover, open to question to what extent factors which influence for example recycling rates or purchase of organic food are likely to apply also to investment in a PV system, which involves a different order of cost.

After a detailed analysis of theories and factors, Stern (2000) concludes that "Environmentally significant behavior is dauntingly complex, both in its variety and in the causal influences on it.". Personal capabilities including financial resources, and contextual factors including costs and rewards, are stronger predictors of behaviours which are expensive or difficult. Such behaviours surely include installation of a PV system. This supports the hypothesis that profitability (reward) is not the only driver of desire for PV, and that financeability is as, if not more, important.

Laroche et al (2001), on the basis of a thorough review of the relevant sociology literature, posit that willingness to pay more for environmentally friendly products may relate to a number of factors, as set out in Table 3 below.

Demographics	Behaviours	Values	Attitudes	Knowledge
Age	Consider envir. issues in purchasing	Individualism	Importance of being envir. friendly	Ecoliteracy
Gender	Recycling	Collectivism	Inconvenience of being envir. friendly	
Income	Buying envir. friendly products	Security	Severity of envir. problems	
Educational level		Fun/enjoyment	Level of corporations' responsibility	
Employment status				
Home ownership				
Marital status				
Family size				

Table 3: factors in WTP for environment friendly products (from Laroche et al, 2001)

Their questionnaire survey (in a North American city) found that of these factors the more reliable predictors of higher WTP for environment friendly products were: gender (female), being married with at least one child at home; perception that ecological problems are severe, that corporations do not act responsibly, that behaving in an environment friendly way is important and not inconvenient; regarding security and warm relationships as important, and often considering environmental issues when making purchases. A 'green energy' marketer in Texas, Green Mountain, views several groups as potential buyers of renewable energy: parents who want to pass on certain values to their children; "global thinkers" who want to give a community lead on issues like global warming; political conservatives who value the independence and economic development benefits of renewables (quoted in Wood, 2005).

Social and moral aspects are significant in environment related consumer behaviour (Jackson, 2005). People are guided by motives besides economic interest, feeling a moral obligation to contribute to environmental improvement (Berglund & Matti, 2006), and individual responsibility to do so, based on other-regarding values of altruism and social justice (Matti, 2008). In a study in Switzerland, Kaiser & Shimoda (1999) found that respondents felt moral responsibility for the environment, which impacted upon their evaluation of personal responsibility. It may in the end come down to what a person believes: "It is at the level of beliefs that we can learn about the unique factors that induce one person to engage in the behavior of interest and to prompt another to follow a different course of action." (Ajzen, 1991).

People can derive personal satisfaction from outcomes about which they care, which could include enhancing the well-being of others and the environment; and from participating in community action to make a difference (De Young, 2000).

Recognition from neighbours may matter less than the feeling of doing one's bit to help the environment, providing intrinsic satisfaction (Keirstead, 2005). Whitmarsh & O'Neill (2010) find self-identity to be an important predictor of environmentally significant behaviour; but also that individual circumstances, such as not owning one's home, could prevent translation of pro-environmental self-identity into corresponding behaviours. External constraints tend especially to limit the effect of general attitudes on behaviour when major investment is involved (Black et al, 1985). Stern (2008) identifies external or contextual forces as often the strongest influences on behaviour. Examples relevant to PV include promotional policies, financial incentives, interpersonal influence, community expectations, information, restrictions on tenants and in the built environment.

Leonard-Barton (1981) examined "voluntary simplicity" values, typically held by persons with environment consciousness and desire for increased self sufficiency and independence - such as are seen among Germans. She found that ".... many voluntary simplicity values are related to .... an interest in at least one alternative energy technology", namely solar thermal (for domestic hot water or heating, as opposed to swimming pool heating). This lends some support to the hypothesis that drivers of desire for solar energy, other than profit motive, operate in populations.

Although some people will inevitably free-ride by sharing in the general environmental and other benefits of others' actions, for instance investment in PV or buying "green power", the actions of the relatively few do not reflect the value that the public as a whole put on renewable energy (Menenteau et al 2003). Ricci et al (2010) found, albeit in the context of how a possible hydrogen economy is understood in certain UK regions, that the sense of responsibility individuals have for their carbon footprints is strongly affected by trust and mistrust towards individuals who might free-ride, business and governments.

3.7.5.3 Demographic factors

According to Fisher & Price (1992), people in higher socio-economic groups are more likely to be early adopters of new technology. However, Peattie (2001) warns that attempts to link environmental concern to demographic factors have produced inconclusive and inconsistent results. On the basis of a survey in the USA, Dietz et al (1998) likewise found an unclear picture with no consistent relationships between demographic factors and environmentalism. The 'Theory of Reasoned Action' of Fishbein (1980) holds that demographic variables can only indirectly affect behaviour, the best predictor of which is a combination of attitude towards the behaviour (including its consequences) with perception of others' thoughts and degree of motivation to comply with them. Results of an early survey in the USA (Laby & Kinnear, 1981) support the hypothesis that adopters and non-adopters of solar energy, in that case thermal collectors for hot water, differ in demographic attributes including age and income level. However, "informed non-adopters", namely those who have considered a solar energy system but decided not - or not yet - to adopt it, are very similar to adopters in terms of those attributes. It is suggested that "informed non-adopters" are "cynical" ; it seems possible that they may instead be cautious, waiting to see how solar hot water systems work before installing one.

Gunter (1998) notes that there are in German speaking countries a large number of older consumers, most in good health, quite well off, and with active lifestyles and often more free time because no longer in employment. It would perhaps be worth investigating the hypothesis that older persons are more likely to adopt PV because they have the time to obtain information, consider options, become involved in local initiatives, and have funds available to invest such as from a retirement lump sum on which investment in PV would provide a better return than typical savings accounts (Herring et al, 2007).

3.7.5.4 Possible drivers of PV purchase

The literature contains several lists of motivations for installation of PV. In the US context, Page (2009) identifies the top drivers, not necessarily in order of importance, as being: environmental benefit especially for our children's sake, saving money, energy independence especially from oil imports, dislike of electricity utilities, shield against grid electricity price rises, statement of values, enhanced status in the community as environmentally aware, 'coolness' of the technology. These are, however, apparently personal opinions not evidently based on research.

A UK study of microgeneration adopters (The Hub, 2005) found that most were committed environmentalists, motivated by the altruistic desire to make a stand for their beliefs, set a tangible example, and be pioneers to help the renewable energy industry grow; a few were technophiles who sought to be self sufficient. Bear in mind, however, that this study predated the UK's introduction of a feed-in tariff.

From a German perspective, Erge et al (2001) concluded that "there must be other reasons why house owners and investors are ready to engage in photovoltaics", since PV is not yet price competitive. They list those reasons as:

- demonstrating to neighbours one's environmental convictions
- environmental benefits of PV as clean energy
- expectation of rising grid prices, and narrowing differential with PV
- innovative financing options to help meet cost of a PV system
- PV usable as a building element, e.g. replacing roof tiles.

Opinions heard by the author in Germany (Stryi-Hipp, 2006; Berg, 2007) are that significant drivers of PV installation are environment consciousness, desire for energy independence, and image - in Rogers' (2003) model, "observability", more colloquially "keeping up with the Müllers".

Principal factors affecting PV purchase decisions by different market groups in Germany, according to a EuPD Research study cited in Neidlein (2009a), are set out in Table 4 below.

Private households	Commercial building	Farmers	Pro investors
quality	price/RoI	price/RoI	price/RoI
guarantee	durability	value for money	availability
		service	

Table 4 : principal factors in PV purchase decision (study by EuPD Research, Neidlein 2009, p.66)

The common thread running through the foregoing commentaries is that return on investment (RoI) is *not* among the principal considerations for private households. That is in line with the hypothesis of the present research that profitability is not a key driver of PV uptake by householders.

Also consistent with the hypothesis is the point made by Gardner & Stern (1996) that, although in most US homes spending money on energy efficiency measures would yield a significantly greater return than a savings account or even stock exchange linked investment, few people undertook such measures. It would seem that they did not think of installation of energy related equipment in terms of a financial investment with the goal of making an attractive return. Other reasons for lack of action included lack of knowledge and information about the technology, where to find installers, and how to arrange financing: those can be relevant also in the case of PV installation.

As Jager (2006) observes, various typologies of needs have been proposed, and "The decision to install a PV system on the roof of a house may .... touch upon the satisfaction of various needs.". Jager suggests that those are as in the left hand column of Table 5 below. In the right hand column are for comparison possible motivations that the present research investigated. There is a visibly high degree of congruence.

Needs affected by PV purchase (put forward in Jager, 2006)	Possible drivers of PV installation, investigated in this thesis
"subsistence": improving environmental conditions in long term	environment consciousness
"belongingness": emulating friends or neighbours	"keeping up with the Müllers"
"participation": collaborating in installing PV	local initiatives and champions
"creation": home improvement	appearing modern, keeping up with technology
"identity": environmental values	demonstrating one's values
"freedom": independence from electricity companies	independence from electricity companies

Table 5 : possible motivations for installing PV, advanced in Jager (2006) and this thesis

The research reported in Jager (2006) is closely akin to that presented in this thesis, being into motivations other than financial for installing a PV system. Jager focuses on a promotional campaign in one Netherlands city (Groningen), which used grants rather than a feed-in tariff. The findings are nonetheless relevant to the drivers of PV build-up in Germany; and the premise that financial support is "a necessary but insufficient condition for the adoption of PV systems" (Jager, op cit, p.1936) is in line with that of this thesis, that financial incentives serve to unleash demand which exists for other motives, rather than create demand from nothing.

3.7.5.5 Intertemporal choice

Jager (2006) succinctly explains the issue of intertemporal choice: people tend to want positive outcomes sooner and to devalue delayed outcomes. To the extent that the positive outcomes of installing PV are delayed, that may deter initially interested persons from deciding to install. In practice, not all positive outcomes are delayed: for instance, visibility and making a statement follow immediately upon installation; and some feed-in tariff income is received from an early stage, as is any feeling of independence from electricity companies. Clearly, however, the bulk of the positive outcomes accrue over a period of years.

Jager suggests that spreading the cost of a PV system over a number of years can resolve the intertemporality problem. Including it in a mortgage is one possible approach, which however normally only applies to new build. House builders in Japan offer a PV roof as a standard option (Nakamura, 2004), but housing stock turnover is much more rapid because of earthquake zone building regulations - typically 25 years, helpfully in line with PV system operating lifetime. Jager does not address the option of obtaining a bank loan to cover much of the cost, which should have a similar effect of achieving a temporal match between payment and positive outcomes. This is significant in the case of Germany, where individuals wishing to install PV on their roof typically borrow 50-75% of the cost, and banks are willing to lend - because the feed-in tariff makes it a very low risk loan (see for instance Hannen, 2009a). This is one facet of how incentives such as a feed-in tariff promote PV by making it financeable.

The guarantee of feed-in tariff income for 20 years should also reduce the uncertainty about future rewards that Roelofsma (1996) contends is a major reason for positive time preference, i.e. intertemporal choice against up front cost for the prospect of future gain. There is a tendency for gains, including environmental outcomes, to be discounted more than losses: see for instance Hardisty & Weber (2009), Frederick et al (2003). On the other hand, Frederick et al also observe that it is erroneous to assume that the same considerations apply to different types of intertemporal choices, and that a single discount rate can sensibly represent all cases. They note that most studies where the size of outcome varied found that people discounted large outcomes less than small ones; as it were telescoping their perception of the value of time periods as they became longer, in "hyperbolic discounting" (see also Angeletos et al, 2003). So if a gain awaited some years hence is relatively large, people may value it more as "worth waiting for", and be more willing to incur a cost now in the expectation of the future gain. That could, in the case of installing a PV system, mean that expectations of return on the investment, because of the long time period involved, are somewhat lower than from a savings account investment over a shorter period (e.g. a 3 year fixed rate bond).

As Webley & Nyhus (2008) comment, "the psychology of intertemporal choice is .... very complex and difficult to study", and theories do not apply in a straightforward way to saving and borrowing. In the case of PV the picture is complicated by the fact that feed-in tariff income means that a PV system starts producing some gain almost immediately, which continues over the short, medium and long terms. There may not be a *net* gain, after loan interest and capital repayment, for several years; thus a further issue is whether the array owner nevertheless perceives the FiT income as a gain. A similarly high cost good like a car will as a rule have much lower residual value in, say, ten years time, and will not earn money during its period of use (disregarding minor exceptions such as taxi driving). A PV system will earn money to offset its purchase and financing costs, and will have residual value in terms of the further FiT income it can earn after loan payback. It is, in any case, not a question of a simple choice between "a smaller sum next week or a larger sum next year", on which many studies of intertemporal choice are based.

Frederick et al (op cit) further observe that discount rates imputed from studies are higher than the prevailing market interest rates. That suggests that people neglect the possibilities of interest on savings, and base their choices on some other consideration - which could include non-monetary benefits of having a PV system, such as a degree of independence and a feeling of contributing to action against climate change. Consistent with that view are studies reported by Meijers & Stafel (2010), which suggest that people will act more sustainably if they think that it will either benefit them in the short term, *or* that there will be a wider benefit, beyond their own interests, in the longer term. The latter is the case with build-up of renewable energy, so this finding may also help to explain the strong support for that. Lewis (2008) points out that the economists' theoretical model of *Homo economicus* acting always out of rational self-interest has been shown to be too simplistic, because people are sometimes sensitive to others' welfare and not solely their own interest. Jackson (2008) agrees: ".... the evidence does suggest very strongly that [price signals and information] are insufficient on their own to facilitate pro-environmental behaviour".

Faiers et al (2007) conclude that: "regardless of how complex an innovation is, there will always be a core of adopters". The 'innovators' and 'early adopters' are committed to the concept, and focused on the long term benefits of the innovation. That implies that the intertemporal choice problem should apply less, if at all, to those adopter groups - to which the householders in Germany who have installed PV are likely to belong.

3.7.5.6 Payback time

As noted above, partial loan financing of a PV installation is common practice in Germany. Typically a loan is arranged such that feed-in tariff income covers capital repayments and interest over a 10-12 year term; see for instance Solarpraxis (2007). After that the PV system belongs to the householder who then benefits from income for the remaining life of the FiT, which runs for any months remaining in the year of installation, plus 20 calendar years; and from the value of PV electricity used in-house after that, saving purchase from the grid at the retail price.

No studies could be found of whether householders regard the time up to repayment of the loan as the simple 'payback time' for the PV system, disregarding the further time required to recover their own capital investment (100% of cost minus the proportion loan financed). The scale of PV capacity build-up in Germany clearly shows, however, that people find the financial terms acceptable.

A survey in the UK by Mark Watson, reported in New Energy Focus (2009), found that 63% of respondents considered seven years a reasonable payback time, and long payback a deterrent to installing PV. Faiers & Neame (2006) report early adopters as considering 10 years satisfactory. By contrast, findings by Scarpa & Willis (2010) indicate that, while households in the UK value renewable energy adoption, their time horizon for microgeneration technology cost is 3-5 years: average willingness to pay for a PV system was £2831, compared with actual cost of £10,638. The cost has since fallen, and a feed-in tariff been introduced in the UK. Actual payback time, like return on investment, is sensitive to PV system cost, output and loan terms. Under present UK conditions it is likely to be 9-10 years.

3.7.5.7 Local initiatives

The key factors identified by Jager (2006) as encouraging diffusion of PV are higher environmental awareness; and information, through helping to reduce perceived technical and administrative barriers, and the complexity involved in the decision. Pedersen (2000) also found information and discussion to be important; and that "green consumption" - by extension, arguably, also other environment friendly actions such as installing PV - "is highly correlated with the degree to which environmental issues are discussed within the social network...". People are influenced by how they see others in their neighbourhood behaving (Durlauf & Young, 2001).

The analysis by Lacey (2008) highlights the importance of clear information about renewable energy, albeit in a US context and including a need to allay fears that it somehow requires living off-grid. Guice (2009) commented that most Americans like the idea of solar energy, but few know enough to make it happen for their home. Imperfect information can slow the diffusion of new technology (Jaffe et al, 2004). It is crucial to get the audience to take information seriously (Stern, 1992), and non-expert friends are an influential source (Leonard-Barton, 1981). Lichter (2010) points out that a PV array is a costly and highly visible item, whose purchase "is one of few cases when private individuals invest in something which must pay for itself /bring in a return."; and that when deciding whether to install PV and if so which system to choose, people in Germany trust the advice of acquaintances (citing a Nielsen survey which gives that advice source 90% approval) and Internet ratings (70%) much more than press articles or advertisements. People may follow the example of neighbours rather than carefully consider the options themselves, as a short-cut to reduce effort (Stern, 2008). Clark et al (2003) found that people attach greater importance to local than to global environmental issues, suggesting that pro-environmental behaviour may be more likely when associated with local concerns. Jackson (2008) observes that: " 'Keeping up with the Joneses' becomes an important livelihood strategy in any society where social position counts.". People tend to contribute more to a public good when they believe that others will do so too, and communication increases motivation to cooperate (Frey & Stutzer, 2008).

These findings indicate that promotion of PV through local initiatives and champions may well be a significant factor in, and driver of, the growth of PV. German sources support that assessment. Chairman of Eurosolar Germany, Dr Axel Berg (an SPD member of parliament with constituency in Munich), has stated bluntly that without the active involvement of regions and communities, climate protection goals are not achievable (quoted in Spindler & Lölhöffel, 2010). The view of one local activist based in Mannheim (Bonnasch, 2005) is that for renewable energy to be successful at the community level four ingredients are essential: political will and/or enthusiasm for renewable energy; community or voluntary initiatives; technical knowhow; and energy price levels which make the renewable alternative attractive. If any of those is missing, momentum and pace of development will falter.

There is a saying in Germany that when three people meet they will decide to found an Association (Verein). This evident propensity to band together for a good purpose is not uncommon in the field of renewable energy, solar in particular. As at 2002 there were already 2610 'Agenda 21' communities in Germany containing 20% of the population, of which 374 in Baden-Württemberg and 701 in Bayern (Diefenbacher et al, 2002). Cities and communities carry a lead responsibility for climate protection; 70% of the population live in towns with under 100,000 residents, where local government is closer to people and well placed for effective action including on renewable energy (Landsberg, 2007). No systematic evaluation was found of the importance of such initiatives at local community level. Anecdotally, however, examples are plentiful, such as the following.

Moosburg is a town of 17,000 population, north-east of Munich. The first PV array was installed there in 1991, and five more in 1996. Their owners began a programme of information and display, which aroused a positive response and led to the founding in 1999 of an Association and an annual promotional event (Stanglmair, 2007). The town has since set itself the goal of 100% renewable energy provision by 2050. The district of **Fürstenfeldbruck** to the west of Munich, with 200,000 population, has the same target, but by 2030 (Baindl, 2010). The 11,000 residents of **Morbach** in Rheinland-Pfalz have gone one better, aiming for 100% renewable energy by 2020 (Grehl & Eibes, 2010).

Gollhofen in north-west Bavaria has a little over 800 residents. The first small PV systems there were installed in 1993 and 1994. Interest grew after introduction of the first feed-in tariff in 2000, installation by the municipality of a large array on community buildings, and establishment of a discussion group (Trabert, 2007). This activity evidently spurred rapid uptake of solar energy, propelling the town to the top of the Solar League (see 4.1.1 below) in 2006.

The city of **Bitterfeld-Wolfen** in Sachsen-Anhalt with population 46,000 wanted to show itself an environment friendly location. But local conditions for household PV were poor in terms of prices, payment conditions and range of systems on offer. So the city launched its own '1000 roofs' PV promotion programme (Photovoltaik, 2009a), 100% financed by the local savings bank at 4.8% interest rate over 15 years. **Fürth, Aschaffenburg** and **Neumarkt** in Bayern launched "100 Roof" PV promotion programmes, offering an all inclusive package with projected return on investment of 4.5% and 15 year complete payback time (Photovoltaik, 2008).

The central German Land of Hessen has a "Competence Network" (deENet) to promote decentralised electricity generation. The town of **Wolfhagen**, with 14,000 residents, is a leading example of local initiatives, having declared the goal of 100% renewably sourced electricity, heat and transport by 2015. Evidence of the town's seriousness is that it has bought back from E.On the local electricity distribution grid, in order to facilitate wholly independent supply (AfEE, 2008).

Local campaigns are also well networked across Germany. As well as Agenda 21 already mentioned, there are the SolarLokal campaign, RegioSolar, the Solar League, regional networks such as the Solarenergieförderverein Bavern, and national organisations including principally Eurosolar Germany and the Solar Förderverein (solar energy promotion association, SFV).

Other approaches to promotion of PV take-up include selling shares in a communal array, often on a public building, known as "Bürgerbeteiligung" (citizen participation). An example is a 1 MWp array in Viersen in Nordrhein Westfalen (Niederrheinwerke, 2008), with projected return on investment of 4-5%. Such schemes enable persons who are interested in PV but unable to install their own system, for instance because their roof faces north or is overshadowed, to own part of a community system. They also, however, prompt the question: why, when various indirect ways to earn a return on investment in PV exist (as described for instance in Hannen, 2010), do so many people go to the trouble of getting their own PV system installed? If because that produces a higher return - is the difference large enough to warrant the effort? Or is this not further evidence that desire for a PV system is not simply about money?
Another model operating in a number of towns is the "Dachbörse", literally "roof stock exchange", which matches building owners with roof space suitable for PV but not wishing to install their own system, and investors seeking to rent roof space on which to install PV. The building owner receives rent, for example €700 per year for a 250 sq.metre roof space (Antaris Solar, 2008), and possibly a greener image, while the investor collects the feed-in tariff income.

Photovoltaik (2009b) reports that retailers in Germany, facing energy costs of €40-50 per sq.metre of floor space, are showing interest in renewable energy as a way to reduce those costs, as well as of presenting a 'green' image and of encouraging customers to do likewise such that they save money and thus have more to spend in shops. An example of such enlightened self-interest is in Heide in Schleswig-Holstein, where a retailer installed 70 kWp of PV on its roof in 2005. (Projected annual output was 62,500 kWh, actual output 69,900 kWh in 2006 and 73,100 kWh in 2007.)

The city of Offenbach am Main, near Frankfurt, proposed an innovative scheme (Freier, 2008) under which residents lacking the funds for a PV system, and perhaps unable or unwilling to borrow, could have a system financed and installed by the municipality. As soon as the city had recovered the cost from feed-in tariff income, it would hand the system over to the householder who would then enjoy the remaining years of FiT payments plus use of PV electricity.

3.7.5.8 Position of tenants

People in rented accommodation may have less freedom to adopt PV. An example of how a landlord's interests can act against those of the tenant is choice of household appliances. The landlord may well choose the lowest priced, rather than spend more on appliances with better energy efficiency, since the tenant has to foot the higher energy bill. (Kempton et al 1992). Lack of landlord's consent was rated quite highly by fieldwork survey respondents as a reason for not installating PV, mean of 4.85 out of 10 (n=155): see Table 23 in 5.1.8 below.

3.7.6 Innovation diffusion theory

3.7.6.1 Rogers' model

A frequently cited theory of the diffusion of innovations is that of Rogers (2003). Briefly, it postulates a five stage process of adoption of an innovation, in this case a rooftop PV system:

⇒ gain initial <u>knowledge</u> of the innovation

⇒ form an attitude towards it (pro or con), through <u>persuasion</u>

⇒ make a <u>decision</u> whether to adopt or reject it

⇒ <u>implementation</u> of that decision, i.e. buy or not

⇒ <u>confirmation</u> of the decision, by not then abandoning the innovation.

The key stage of 'persuasion' is affected by the perceived characteristics of the innovation in terms of its *relative advantage, compatibility, complexity, trialability*, and *observability*. The pattern of diffusion described by Rogers can be portrayed as a bell curve, plotting the number of adopters of the innovation in each time interval; or as an S-curve plotting cumulative adoption. The latter probably better illustrates the varying rate of PV capacity growth in different stages. Those stages too are five in number: 'innovators' (2.5% of eventual adopters), 'early adopters' (13.5%), the 'early majority' (34%), 'late majority' (34%), and 'laggards' (16%). The diffusion curve does not, of course, purport to show what proportion of a population of *potential* adopters actually buy or decline to, only the rate of actual adoption over time.

Rogers describes 'early adopters' as locally embedded, known and respected; the role models whom others consult and to whom they look; whose adoption of an innovation gives it a seal of approval and triggers mass adoption (Rogers, 2003, p.283). That description could fit the members of local initiatives to promote PV, especially if they include prominent members of the community. Of the 56 survey respondents (Chapter 5.1) who rated 'local initiative' highly (8-10 out of 10) as a reason for wanting a PV system, only 10 have postcodes in the sunnier south of Germany. Further research into whether the existence of such an initiative correlates with higher than average adoption of PV could be of interest.

Labay & Kinnear (1981*) suggested a category of "informed non-adopters", who differ only slightly from adopters in perception of innovations, in being "cynical" - not the same as "cautious", since rather than waiting for and then emulating earlier adopters, this group identify logical grounds for not adopting at all. (* The first edition of Rogers' "Diffusion of Innovations" was published in 1962.)

Faiers & Neame (2006) report the findings of a survey in the UK of pioneer adopters of solar energy systems (thermal and PV), and of others who were interested but did not adopt. They argue that 'innovators' and 'early adopters' are committed to the concept of the innovation, and will tolerate shortcoming because they are focused on the long term benefits. For them, cost is not a determining factor; the value of the innovation to them as individuals matters more (Garling & Thorgorsen, 2001). A particularly interesting finding is that those interested in solar and thus candidates to be 'early majority' adopters, but who did not adopt, were clearly negative in their perception of affordability, grant support, and payback period - regarding a maximum of 10 years as an "attractive" period. Actual early adopters differed in being neutral on the first two criteria and negative about payback period, which did not, however, deter them from adopting. In Germany the feed-in tariff mechanism removes the obstacles of lack of affordability and support, and long payback time. That implies that progression from 'early adopters' into the 'early majority' stage may be expected to occur.

Keirstead (2006) considers that Rogers' five characteristics of an innovation at the 'persuasion' stage, as described above, are in the case of PV compared with existing grid supply of electricity almost all *against* adoption of PV. His focus was, however, on the UK before its introduction of a feed-in tariff in 2010. In Germany the provisions of the Renewable Energy Sources Law remove all of the difficulties that Keirstead perceived, as set out in Table 6 below.

Innovation characteristic	Assessment in UK, 2006	Assessment in Germany
relative advantage	small	provided by feed-in tariff, in financeability + return on investment
compatibility	poor	guaranteed grid access
complexity	greater	well established base of information + installers
observability/trialability	difficult, as market penetration low	not difficult, market penetration significantly higher

Table 6 : comparison of evaluation of innovation characteristics for PV in the UK (as in Keirstead, 2006) and in Germany

Nonetheless, Keirstead's suggestion that 'innovators' and 'early adopters' are distinct from the 'early majority' accords with that of Faiers & Neame (2006), who refer to the "chasm" between the two groups of adopters; and with Geroski (2000), who points out that the earliest adopters do so without benefit of the experience of previous users, implying that they must in some way differ from subsequent adopter groups.

Kaplan (1999a) critically reviews the Rogers model of innovation diffusion (Rogers, 1995, 4th edition). He contends that "knowledge" as a factor in diffusion is insufficient, since it is possible to know about PV yet not adopt it. He proposes a refinement of the model to add "familiarity", reflecting the importance of information, knowledge and experience of an innovation. Kaplan's focus is, however, on managers in US electric utilities. Does his concept of "familiarity" apply equally to individuals' decisions about buying into an innovation, such as PV? That seems open to question: resistance to something new is likely to be stronger among managers in an organisation, commonly referred to as the "not invented here" syndrome, than among individual consumers. At least some consumers are willing more or less swiftly to embrace an innovation - as Rogers' model describes.

Geroski (2000) suggests that what he calls a 'probit' model may be appropriate for innovation diffusion, in which the rate of adoption rises as the innovation's price falls and profitability increases. It is, however, questionable whether that is applicable to PV in Germany since regular reductions in the feed-in tariff rate offset falls in PV system prices. On the other hand, the steep drop in prices in 2009 following collapse of the Spanish market and glut of modules was accompanied by a surge in demand.

Oliver & Jackson (1999) describe another alternative model of PV diffusion, through "ever expanding niche markets", in each of which PV becomes economic as its costs fall in response to the increase in demand, which opens up the next niche in a series of stepping stones to the mass market. For a description of Strategic Niche Management see Smith (2003).

3.7.6.2 Innovation adoption in Germany

With regard to technical consumer goods in general, Germany appears to lie in the middle ranking of countries by propensity to adopt innovations (Lynn & Gelb 1996). How far this finding is applicable to purchase of PV arrays is, however, unclear. Fischer (2004) investigated the characteristics of pioneer adopters in Germany of micro CHP systems, corresponding to Rogers' 'innovators' category. Their demographic profile was very uniform: male, in upper middle age bracket (mean age 54.9) and higher income range, of higher educational level, in a technical profession, owning their own house (mostly) or apartment, living in small towns of fewer than 20,000 residents (82.5% of 'Solar League' towns are in that category), taking environmental issues seriously. Many had already installed other environment-friendly equipment such as insulation, energy efficient appliances, solar thermal and PV systems.

According to the analysis in Berger (2001) "cost covering tariffs", as operated in some German cities prior to the feed-in tariff introduced in 2000, supported a higher rate of PV capacity build-up. That is in line with the hypothesis that financeability matters more than profitability ; while acknowledging Berger's caveat that build-up pre-2000 was still only reaching the "innovators" category in the innovation diffusion theory of Rogers (2003).

3.8 Conclusions

The review of the literature found no studies specifically about what motivates people in Germany, in particular individual households, to install PV systems - beyond the widespread assumption that the "generous" feed-in tariff drives demand, implying that the prospect of lucrative returns on investment is the motivation. Nevertheless, some support was found for the hypothesis that financeability matters more to potential buyers of PV systems than does high return on the investment.

There is a great deal of research about "green" behaviour, but once again little relating directly to take-up of PV, and that confined to surveys of attitudes towards renewables including solar energy. The literature on innovation diffusion offers no clear consensus on the profile of environment-friendly persons, let alone of PV adopters, although there are some indications that concern about climate change and future generations, and desire for independence from large utilities, may be drivers. Studies on intertemporal choice in purchase decisions provide some relevant insights, but barely address high cost items comparable to a PV system.

It is, accordingly, believed that the data analysis and other research presented in this thesis will help to fill in those gaps, and thereby contribute to expanding knowledge in the field.

Chapter 4 : Methodology and Method

4.1 Test for correlation between PV capacity and expected return on investment

Aggregated data are available from government websites on total PV capacity installed in Germany by Land. Data on capacity by 'Kreis', corresponding to the district sub-division in UK local government, would be obtainable e.g. from EuPD Research - but for purchase at a cost well beyond the author's budget. Fortunately, a usable set of PV capacity data is freely published on the Web, comprising hundreds of German cities, towns, and villages which take part in the "Solar Bundesliga" ('Solar League'), an informal competition as to which community has the most solar energy capacity relative to its population.

4.1.1 The 'Solar Bundesliga'

The "Solar League" in Germany was founded in 2001 as an informal competition comparing the development of solar energy as between German villages, towns and cities. It is a joint venture of 'Solarthemen' (Verlag Bröer & Witt GbR) and the environmental organisation Deutsche Umwelthilfe e.V.. Motivation for a town to participate may include a sense of prestige, a desire to benchmark, and the possible marketing value of a high place in the League. The League's scoring system covers both solar thermal and PV capacity. Since the research concerned only PV, the 74 out of the 1283 participating towns which had no PV capacity were removed from the dataset, leaving for the 2008-09 "season" a dataset of 1209 towns with total population of 29.5 m and 750 MWp installed PV capacity.

It was necessary to consider whether this is a self-selecting group of pro-solar towns, meaning that the data are biased. The conclusion reached was that it is not. The large number of towns involved constitute a substantial sample, encompassing over one third of the population of Germany. The wide range of PV capacity in those towns, in 40.3% of cases below the overall League average of 25.4 Wp/Resident, suggests a representative cross-section of communities.

4.1.2 Variables

Expected return on investment depends on a number of factors, chief among which are: cost of array, projected array output, feed-in tariff rate, proportion of total array cost financed by borrowing, interest rate, and length of loan term.

It would be beyond the scope of this research to attempt to identify and take account of local variations in PV module and installation costs. Instead, it is assumed that the German market is mature and competitive enough that there is a "going rate" for PV array cost applicable throughout the country, expressible in Euros per kilowatt-peak (€/kWp) capacity inclusive of installation, for a given array size category, in this case small rooftop. The feed-in tariff for PV is fixed regardless of location. Interest rate on a loan for PV array purchase is taken to be uniform, because the guarantee of feed-in tariff income makes the loan low- or zero-risk from banks' point of view.

Proportion of array cost borrowed, and loan term, are of course matters for individual choice. They are thus among the variable input factors of which to take account in sensitivity analysis of expected return on investment: see 4.2 below. For the purposes, however, of testing the degree of correlation between PV capacity and expected return, it seems an acceptable simplification to control for the loan related factors, by assuming that all purchasers of household rooftop PV arrays obtained loan finance on a standardised set of terms (whatever those be – for example, 75% of cost borrowed, at 4% interest over 15 years). A further simplifying assumption is that private individuals considering purchase of a PV array focus on whether they will get their money back, how long it will take (simple payback time), and whether the investment will earn a return comparable to what they could get by putting it in a savings account - and therefore that they do not embark on more sophisticated analysis, as a professional investor would, of discounted cash flow and internal rate of return.

The only remaining variable is projected array output, which one may accordingly take as direct proxy for expected return on investment, since a given annual output in kWh multiplied by the feed-in tariff rate gives the income, to set against array purchase and financing costs. A straightforward spreadsheet model then produces the expected return on investment.

4.1.3 PVGIS

An easily accessible and reliable source of the projected output of a PV array in a given location is the Photovoltaic Geographical Information System (PVGIS) set up by researchers at the EU Joint Research Centre at Ispra in Italy. It is a database of output estimated on the basis of historical satellite data on insolation, and parameters of array efficiency, orientation and angle of tilt. Comparison of estimated output with actual observed output at Ispra indicates that the PVGIS database is accurate to circa 3% (Kenny et al, 2006). It is necessary only to input a town name and country; a map display of the location enables cross-checking, for more common placenames, that the intended one is selected. The investigation of correlation between projected output, as proxy for return on investment, and size of installed PV capacity was based on output data from PVGIS for the 1209 communities participating in the Solar Bundesliga as of its 2008-09 "season" which had PV capacity installed, using the standard default parameters (polycrystalline silicon modules, 12.5% array efficiency, oriented due south at optimal angle of tilt).

4.1.4 Assembly of the dataset

The data on installed PV capacity and number of residents for each of the towns in the 2008-09 Solar League were obtained from the League website: as the website lists only 25 towns per page, this was a painstaking exercise of repeated cutting and pasting into a spreadsheet. To the spreadsheet were then added the projected array output data, in kWh per kWp installed per year, obtained by looking up each town on the PVGIS website. In a number of cases there are several towns in Germany with the same name. Since the League data include in which Land a participating town is, the PVGIS map display made it possible to ensure selection of the correct town among several across Germany. In a handful of cases of more than one town with the same name *and* in the same Land, it sufficed to check the population stated on each town's website against that listed in the League data. It was then a simple matter to sort the data in various ways: in alphabetical order of town name, by Land, by projected array output, and combinations thereof. The results of this investigation were published in Plater & Boyle (2009).

4.1.5 Tests applied

First a simple scatter plot was made of PV capacity (in Watts per Resident, x-axis) against projected PV system ouput (in kWh per kWp capacity per year, y-axis). The Watts per Resident metric was used in order to normalise for town population.

Then the following Spearman rank correlation tests were carried out, on various aspects of the relationship between where the PV capacity was installed and projected PV system output as proxy for expected return on investment.

- PV capacity data from all Solar League towns in each of ten bands of 30 kWh/kWp/ year projected array output were aggregated, then the

Spearman rank correlation coefficient r_s calculated. The purpose was to focus closely on the key variants of interest, namely projected array output and size of PV capacity installed, across administrative boundaries; and aggregated to reduce the effect of any local factors (such as presence of a 'champion' or promotion initiative for PV).

An issue regarding this test is that defining a precise 30 kWh band, for example 910-939 kWh/kWp/year, inevitably means that there is a sharp boundary at each end of the band. Some towns are only outside the lower or upper boundary by a few or even a single kWh. Those towns may have markedly more or less PV capacity than the towns just the other side of the boundary and inside the band in question. Therefore it is conceivable that moving the boundary very slightly could significantly alter the total PV capacity of towns in respective bands. It was assumed, however, that any such changes at the lower and upper boundaries of each band would cancel out to a sufficient extent that relative capacities did not significantly change.

- Calculation of r_s for *total* PV capacity in the towns in each 30 kWh array output band, i.e. without normalising for population.
- Calculation of r_s for the increase in number of towns from each Land participating in the League in 2008 compared with 2004. (13 pairs, excluding the single city Länder - Berlin, Hamburg, Bremen - which are in the League but by definition only contain one town in each Land, so the number of towns clearly could not increase.
- Calculation of r_s for the increase in total PV capacity in League participant towns in each Land (16 pairs, including the single city Länder).

Calculation of r_s for the percentage increase in PV capacity in League towns in each Land (16 pairs).

Maximum and minimum projected array outputs among League towns in each Land were compared, to check to what extent each Land is uniformly "sunny", in particular those with large surface area and those in the South.

4.2 Analysis of sensitivity of expected return to input factors

4.2.1 Introduction

To complement the correlation test described in 4.1 above, an analysis was carried out of the sensitivity of return on investment to input factors such as array cost, financing terms and once again projected array output hence feed-in tariff income. The aim was to examine what, if any, proportion of PV capacity was installed in locations where the expected return on investment was high, similar, or low by comparison with typical savings account interest rates.

Return on investment depends on the size of net profit in relation to the amount of own capital invested. Net profit is the difference between income, which is solely from feed-in tariff payments, and costs, which comprise several elements. The sensitivity analysis spreadsheet developed incorporates variable factors to input, and dependent elements derived from the input variables.

Variable input factors

- array size, array cost per kWp (including balance of system components and installation), and hence total array cost
- projected array output in kWh (from PVGIS estimator website)
- feed-in tariff rate, in €cents per kWh (rate for rooftop arrays up to 30 kWp)
- percentage of array cost financed with own capital, and percentage borrowed

- interest rate (assumed to remain fixed for the loan period)
- loan period (in years)

Dependent elements

- amount borrowed = total array cost x percentage borrowed
- investment = total array cost x percentage own capital
- annual loan repayment (assumes fixed) = amount borrowed / loan period
- interest = amount borrowed x interest rate (calc. over loan period)
- maintenance and insurance = 1% x array cost x 20 years

Assumptions: tax paid on cost of array, so not on feed-in tariff income ; cost for inverter replacement, if any, is covered by maintenance allowance and income in months before first calendar year (of 20) of FIT payments; no degradation of array output over time.

The average installed price per kWp, installed, of a small (<10 kWp) PV system in each year from 1999-2010 is shown in Table 7 below.

year	price (€)	price *inc* tax
1999	7320	8491
2000	7420	8607
2001	8350	9686
2002	6420	7447
2003	4680	5429
2004	4750	5510
2005	4990	5788
2006	5160	5986
2007	4660	5545
2008	4200	4998
2009	3220	3832
2010	3010	3582

Table 7 : average installed price per kWp of a small (<10kWp) rooftop PV system; tax 16% until 2006, 19% from 1 January 2007). Source: EuPD Research, Bonn.

The upward blip in 2005-2006 resulted from a shortage of solar grade silicon which sharply increased the cost of that element of system cost.

4.2.2 Initial analysis

Initially a simple analysis was carried out using the 2008-09 Liga dataset, FiT rate (€0.4675 per kWh) and array cost (€5000 per kWp installed, inc. tax), and only two combinations of variables: 75% of array cost borrowed, at 4% interest, over 12 years and over 20 years respectively.

A refinement would be to apply modelling to the *new* PV capacity added each year, in each of the Solar League towns, identified from the League's archive of data, so that the applicable FIT rate and array cost were those which obtained in the year in which a PV system was installed. It would, however, be a time consuming process to sift out the new capacity across so many towns. For the purpose of this analysis it was assumed that PV system cost and FiT rate had stayed reasonably well in balance, so that the precise year of installation of each component of a town's PV capacity made no significant difference.

4.2.3 Fuller analysis

4.2.3.1 Scope

For greater thoroughness and as a further small contribution to research in the field, it was decided to carry out a fuller sensitivity analysis in the second half of 2010. This one involved a larger number of combinations of input variables, and used the Solar League dataset for both its 2008-09 "season", when 1209 German towns participated which have some PV capacity installed (as before, those with only solar thermal capacity were omitted); and its 2010-11 season, for which the League comprises 1516 towns with PV capacity.

The League dataset provided town name, Land, number of residents, and PV capacity in Wp per resident, from which total installed capacity was calculated.

The feed-in tariff rate used was that in force from January-June 2010, €0.3914 per kWh. A supplementary in-year reduction took place in two stages: 13% from July, and a further 3% (of the January-June rate) from October. That will be taken into account in discussion of sensitivity analysis results. Projected PV system output for each town, in kWh per kWp capacity per year, was obtained as before from the PVGIS output estimator website.

4.2.3.2 Input variables

PV system price was set from Table 7 on page 125 above at €3582 per kWp, installed and including tax. Various values for other variables were used, as in Table 8 below, giving a total of 48 combinations tested.

Proportion of system cost borrowed	50%	66.7%	75%	
Term of loan (years)	10	12	15	20
Interest rate	3.5%	4.0%	4.5%	5.0%

Table 8 : values of input variables applied in sensitivity analysis of expected return on investment in a rooftop PV system in 2010

4.2.3.3 Derived variables and outputs

<u>System cost</u>: 4 x price per kWp (a typical rooftop PV system is around 4 kWp)

<u>Own capital employed</u> (OCE): ((100 - % borrowed)/100) x system cost

<u>Interest</u>: system cost x (% borrowed/100)/2 x interest rate x loan term

<u>Cost</u>: (system cost x 1.2) + Interest

<u>Income</u>: PVGIS projected output x 4 (kWp) x 0.95 x FiT rate x 20 (years)

<u>Return on investment</u> (RoI): (Cost - Income) / OCE x 100

4.2.3.4 Explanations

The ' /2 ' term in the formula for Interest payable derives from the fact that total interest calculated annually, on a loan balance which reduces through equal annual repayments of capital, is the same as interest calculated on a fixed sum equal to the balance at the midpoint of the loan term.

The ' 1.2 ' term in the formula for Cost allows for operating costs for maintenance (to include any inverter replacement), insurance etc at 1% per year for the 20 years feed-in tariff lifetime. Solarpraxis (2007) puts "operating costs" at 1.5% per year, but that seems a little too high: maintenance should be minimal, inverter reliability is now very high, and insurance inexpensive. Perhaps the Solarpraxis figure includes notional cost of time spent on paperwork, e.g. reporting of output to the federal grid agency.

The ' 0.95 ' term in the formula for Income is explained in 4.3.2.5 (2) below.

The expected return on investment (RoI) is first calculated as total RoI over the 20 year feed-in tariff lifetime, then converted via a look-up table into the equivalent annual compounded RoI, for comparison with 'high street' savings account interest rates (see Chapter 5, Results & Analysis).

4.2.3.5 Assumptions

(1) <u>Feed-in tariff rate</u>

The latest Solar Bundesliga 'season' runs from 2010 to 2011. It is not clear what proportion of the capacity recorded for each participating town was installed in previous years, in 2010 before the season began, or during the course of it. To simplify the sensitivity analysis somewhat, the model assumed that the January-June 2010 rate of €0.3914 per kWh applied to all capacity.

From federal grid agency data the total new capacity installed from January-June 2010 was 3853 MWp, and 1526 MWp from July-September after the additional in-year cut in the feed-in tariff (FiT) rate, referred to above. (Data were not yetavailable for October-December 2010.) An average FiT rate for January-September 2010 weighted by capacity installed would be (0.3914 x 3853) + (0.3405 x 1526) = 2027.7 / 5379 = €0.377 per kWh, 3.7% lower than the January-June rate.

Running the model, as a check, with that FiT rate for the ' 75% borrowed over 12 yrs at 4.0% ' combination produced expected RoI 0.5% lower, which suggests that the FiT cut from July 2010 had an effect. That said, the weighted average RoI is still fairly high at 5.51%. Moreover, it is debatable whether it would be appropriate to apply the lower FiT rate from July 2010 to all PV capacity in the Solar League towns, some of which was installed before 2010. Ideally each year's prevailing FiT rate would be applied only to the capacity newly installed in each town in that year; but as noted above it would be a major undertaking to calculate that figure for a large, and annually increasing, number of towns.

(2) PV system output

The spreadsheet model included an element for degradation of PV system output over 20 years. Module producers guarantee a maximum degradation from initial capacity of 0.75% or 0.7% per annum (Isofotón advertisement in Photovoltaik 12/2010, p.23), so one may assume that in practice it will be lower to leave themselves a safety margin. Accordingly 0.5% per year appears reasonable.

A possible simplifying assumption was considered, namely that the system would continue to generate beyond the 20 year FiT period, and that the resulting saving, through using some of the PV electricity in-house instead of buying in at grid retail price, would offset loss of FiT income because of output degradation.

However, such a prospective financial bonus 20 years hence is, in terms of intertemporal decision making, on a distant horizon and liable to be disregarded. It was accordingly thought better to run the model with an added term in the Income formula for output degradation, set at 0.95, since a linear annual degradation of 0.5% over the 20 year period produces a total degradation of cumulative output of 5%.

4.3 Fieldwork survey

4.3.1 Introduction

As explained in Chapter 2.3, this survey was the principal means of testing the main hypothesis:

> H_1 Financial incentives, primarily the feed-in tariff, have catalysed the rapid build-up of PV in Germany, not so much by making it *profitable* as by making it *financeable*.

The aims were to identify any other drivers of desire to install PV among German residents, to assess their importance relative to the financial incentive provided by the feed-in tariff, and to differentiate the latter's effects as between making PV profitable and making it financeable.

4.3.2 Survey questionnaire design

The main challenge in conducting the survey, from the UK but of people resident in Germany, was to obtain sufficient responses to enable valid statistical analysis. To improve the prospects that people in the survey areas would take the time to complete the questionnaire, it was desirable to keep it short, straightforward and quick to fill in. The final questionnaire, in its printed form, consisted of just two sides of A4. This was converted to a Web based online survey, in which all questions were identical to those in the printed questionnaire. The single difference was that the online survey was constructed, using conditional branching features in the software, to guide the respondent through the correct sequence (see below for details of questionnaire content). The questionnaire was, of course, in German. The text was checked for correctness of language by native German speakers, both personal friends and one member of Open University faculty. Ethical approval was granted by the committee chairman, after consideration of a formal application giving full details of the survey.

The questionnaire consisted of the following three sections.

(1) *Attitudinal statements*

This section was designed to obtain an indication of the respondent's level of environmental responsibility, as an additional parameter in subsequent analysis. It presented ten statements, in no obvious order, and asked the respondent to state the extent to which he or she agreed with each. Five options were given: a four point Likert scale of "Fully agree", "Somewhat agree", "Neither agree nor disagree", "Disagree"; and a "Don't know/care" option. Five of the statements were consistent with a more positive attitude, in relation to concern about environmental problems; the other five with a more negative attitude. The statements were not, however, grouped in pairs i.e. positive/negative on a given issue, but presented in jumbled order. For purposes of analysis the statements were labelled A-J, then grouped into the 'positive' five A, D, G, H, J and the 'negative' five B, C E, F, I.

The choice of statements was inspired by several sources:

- de Vaus (2002), pp. 95-96 advice on questionnaire construction with reference to statements to gauge attitude ;

- the New Ecological Paradigm set of statements designed to gauge pro- and anti-environmental attitudes, as revised by Dunlap et al (2000);

- Eurobarometer (2008), whether climate change perceived as a serious danger ;

- Kuckartz & Rheingans-Heintze (2006), p.25 Table 4, survey questions about intergenerational equity and what we will leave our children, responsibility of politicians, technofixes vs reduction in living standards, scope for individuals to help the environment ;

- Dunlap et al (1993), on willingness to pay more for environmental benefit, and the role of individuals:

- arguments put forward by critics of renewable energy, regarding the cost of support, and that emissions by e.g. China make effort in Germany futile.

(2) *Reasons for wanting, or not wanting, to install PV*

This section set out a number of possible reasons for (a) wishing to install a rooftop PV system, (b) not installing PV, and (c) not wanting PV. It asked the respondent to assign an importance score to each, in the range 1-10 where 10 meant "extremely important", with a "don't know" response also allowed. The aim was to cover all main reasons, both psychological (e.g. environment consciousness) and practical (e.g. direction of roof facing, shading). Ideas on aspects to include came from advice given by solar promotion initiatives and publications like Solarpraxis (2007); views on climate change especially in Kuckartz & Rheingans-Heintze (2006); information on housing in Germany (see Table 36 in 6.4.4.1 below); and of course the wish to test the hypothesis that financeability of a PV system matters more than its profitability, through statements explicitly addressing those factors.

In addition there was the possibility to write in other reasons, not listed in the questionnaire, and rate them in the same manner.

The preamble to this section gave instructions on which set(s) of reasons to rate.

* Case (i): a respondent who already had a PV array, or had decided to have one installed, was directed to rate set of reasons (a).
* Case (ii): one who would like to have a PV array, but was unable to or faced obstacles, was directed to rate *both* sets of reasons (a) and (b).
* Case (iii): one who did not want to have a PV array was directed to rate set of reasons (c).

In the online survey the respondent was first asked to indicate which of Cases (i), (ii) or (iii) applied. The software then automatically took the respondent to pages containing the appropriate set(s) of reasons to rate.

(3) *Demographic data*

This final section asked the respondent to provide basic categorisation data, by ticking the appropriate box among a range of bands or options. The categories were:

Age - select one of six bands from 11-24 years old, to over 74 years

Family status - either 'single' or 'married/living together' ;

Children - either 'have' or 'do not have' (without asking for number or ages) ;

Educational level - four options, approximating to GCSE, A-level, higher education, and "other" ;

Income - seven bands, from 'up to €15,000' to 'over €90,000', or decline to state ;

Political affiliation - select one of the six main parties, 'other', or decline to state;

Gender - male or female ;

Postcode - at least the first three digits, out of the five in a full German postcode, sufficient to identify which town.

The purpose of requesting the postcode was to identify the respondent's location, within limits narrow enough to make possible estimation of the projected PV array output parameter, but without asking for the precise address as that would have raised problems in relation to data protection law.

It was decided to conduct random sampling, by publicising the survey and inviting responses. This was for several reasons.

- German data protection laws are very strict, and people are reluctant to give information in a way which could identify them, such as being interviewed.

- By making responses anonymous it was hoped to improve the prospects that participants would give frank answers, rather than seek to present themselves in the best light or say what they think the researcher wants to hear.

- Practicability and cost. Travel to Germany to conduct interviews and/or distribute questionnaires by hand, or engaging a market research organisation to do so, would have involved considerable expense. (The research was self funded.)

For the same reasons of practicability and cost, it was further decided to make the survey primarily Web based. An additional reason was to make participation easier and cost free. Some printed questionnaires were distributed, for use as an aide-mémoire and/or template for later online completion of the survey.

The statements and questions used in the survey are at Annex A, in the original German with translations.

4.3.3 Conducting the survey (1) : initial frustration

A series of attempts to obtain survey responses, extending over more than a year and from southern to northern Germany, proved abortive. The main reasons were that help in disseminating printed questionnaires, promised by several acquaintances of the researcher, either was not in the event forthcoming or produced poor results; and that of the few responses received, many were incorrectly completed but errors were not rectifiable because the anonymous nature of the survey prevented return of questionnaires to those concerned.

(2) : eventual success

In the course of monitoring German sources of information, a website was discovered which conducts surveys across Germany on PV related topics: www.photovoltaikumfrage.de, based in Freiberg in Sachsen. An e-mail enquiry to the website owner produced a positive response: he was willing not simply to carry a link to the survey, but to go further and run the survey on his own website, and without charge as a contribution to research. It was decided to offer a single prize of €50, to go to one respondent picked at random, in line with established practice of the website as an incentive to participate. In the event, the winner asked for the prize to be donated to a children's charity.

This proved to be the long hoped for breakthrough. The survey went live on the website in September 2010, and ran until late November by which point exactly

400 responses had been received. All were checked for completeness and validated. Since the number of responses was satisfactory, and they were obtained in a single and short period of time, it was decided to conduct data analysis on the resulting dataset, and to leave aside the few previously obtained and valid responses in view of the highly protracted collection period, and of developments in the meantime in German politics and in the PV market, including fall in system prices and surge in capacity growth.

4.3.4 Methodological issues

(a) Is there a risk of sample bias because respondents were self-selecting, meaning that those favourably disposed towards PV were more likely to participate?

This problem is difficult to avoid, without constructing a representative cross-sample of the population as a professional polling organisation (e.g. Mori) would do - which as noted above was beyond the researcher's resources. The survey was conducted on a website with national reach. The postcodes given by respondents confirm that participation was from all over Germany.

That said, opinion polls show that approximately 80% of Germans are in favour of PV; see most recently forsa 2009a. Accordingly, any sizeable subset of the population is in any case likely to share that attitude. On the other hand, residents had motivation other than pro-PV attitude to participate, namely the possibility of a small cash prize. Further, "negative" responses viz. from people who do not want PV, were also of value in understanding motivations.

It should be acknowledged that 46.5% of respondents support opposition political parties, including 24.0% for the Greens, and only 29.8% support those in the current government coalition. On the other hand, those percentages for Greens and the opposition as a whole do not diverge markedly from opinion polls in late

2010. Moreover, 17.8% declined to state their political allegiance, so there is margin for error in the relative proportions.

(b) Does use of a Web-based survey risk biasing the sample?

De Vaus 2002 considered that "internet samples are unlikely, at the present stage, to be representative of the general population", adding however that that "does not mean that they have no value or future". Those observations were, however, in the context of rather more limited Internet access than is now the case, with at the time markedly higher access rates among younger people, managerial and professional occupations, and those with higher education qualifications.

Access is nowadays commonplace: as at December 2009, according to the German federal statistical office 73% of households in Germany had Internet access, and 82% of those households had broadband connection (DeStatis 2009). The corresponding figure for 2002 was 46% of households with access (DeStatis 2006). Internet access seems therefore unlikely to be a significant issue. Examination of survey respondents' demographic profiles reveals no sign of bias which might relate to Internet access. For example, 26.0% are in the ≥55 age band, 25.5% in the lower income range, and 51.0% of lower educational attainment (GCSE equivalent).

(c) Is the sample size large enough?

Points of particular relevance from the discussion of sample size in de Vaus (2002) are that a minimum sample of 400 is needed to keep the sampling error to 5% ; and that each subgroup, such as age band or voting intention, should contain at least 50-100 cases. There is a minor qualification: that if the sample is "a sizeable proportion of the population (e.g. 10 per cent)" then a slightly smaller sample is equally accurate, and a 'finite population correction' can be applied to find adjusted sampling error.

The sample size of 400 obtained in the (autumn 2010) survey is considered satisfactory in this regard. The principal sub-populations subjected to variance and correlation tests - those who have or will get a PV system, those who want one but are unable to install, and those who do not want a system - each comprise at least 50. Naturally, groups fitting combinations of response and demographic factors will be smaller the more such factors are involved. For example, middle aged persons in the higher income range who have children and rate return on investment as more important than contributing to climate protection, number just 5.

That is one reason why it would have been preferable to achieve a larger sample size. The number of responses was, however, the best that considerable effort could obtain. A low response rate is not too surprising. On the basis of everyday experience, in practice few people will put aside a questionnaire for later completion; they will tend to complete it either straight away, or not at all.
The sample size compares quite well with that in Schweizer-Rees 2008 (n = 458, total from three locations 105, 188, 165).

4.4 Other data obtained and examined

Data on annual new installations by PV system size were obtained, from EuPD Research and the German federal grid agency. See 6.4.4 below for discussion of those data in terms of market segmentation, with particular reference to household rooftop systems. That includes examination of the year to year progression of the number of PV arrays installed to date in Germany in that segment, and how it compares with the diffusion pattern described in Rogers (2003).

Chapter 5 : results and analysis

"Get your facts first, then you can distort them as you please." Mark Twain

5.1 Fieldwork survey

A total of 400 responses were received to the online survey. Space limitations on the present thesis rule out a fully comprehensive analysis of the resulting substantial dataset. Analysis was accordingly focused on aspects relating to possible drivers of PV capacity growth, and to the relative importance of financeability (the feed-in tariff making it feasible to finance a rooftop PV system) and of profitability (the FiT providing an attractive return on investment). The full dataset will, however, be deposited in the ESRC archive at the University of Essex, as a further contribution to research in the field.

The 400 responses divided into three groups:

(1) persons who have installed a rooftop PV system or decided to do so, n = 192

(2) those who would like to have a PV system, but are unable to install one or have decided not (or not yet) to do so, n = 155

(3) those who do not wish to install PV, n = 53.

5.1.1 Environmental Attitude testing

Before commencing analysis of the survey data, one further variable was created, based on respondents' replies to the set of ten statements in the first part of the survey questionnaire, designed as described in Chapter 4.3.2 to elicit information about their environmental attitudes.

Scores were assigned to replies as set out in Table 9 overleaf.

	Agree fully	Agree somewhat	Neither agree nor disagree	Disagree	Don't know
'Positive' statement	4	3	2	1	mean of scores for other responses
'Negative' statement	1	2	3	4	

Table 9 : scores assigned to responses to statements relating to individual environmental responsibility

Testing for unidimensionality of the scale, as advised in de Vaus (2002) p.184 and in Petty & Cacioppo (1996), generated an item-to-scale correlation coefficient (Pearson's r , as calculated by the Excel CORREL function) of above 0.3 for nine of the ten statements, the coefficients ranging from 0.313 to 0.550 for the whole dataset of 400 responses, as in Table 10 below. Individual testing of each of the three groups of responses produced very similar coefficients.

'Positive' statements	correlation		'Negative' statements	correlation
A	0.375		B	0.439
D	0.460		C	0.550
G	0.357		E	0.332
H	0.427		F	0.170
J	0.313		I	0.507

Table 10 : item-to-scale correlation coefficients for responses to statements testing individual environmental responsibility, for the whole dataset (n = 400)

The exception was the statement "For my mobility I need a car with good performance", which was sixth of ten in order of presentation in the survey. For that statement the item to scale correlation coefficient was only 0.170 ; and 0.270 even when compared only with other environmentally 'negative' statements. In the light of this, that statement was removed from the set. That necessitated recalculating the scores assigned to "Don't know" responses as the mean of those for the remaining nine statements, since both total score and divisor had changed. From the responses to the remaining nine statements an environmental responsibility index (ERI) for respondents was calculated.

That the 'mobility' statement was the only one inconsistent with the scale may reflect an ambivalent attitude among Germans towards cars. It is noteworthy that even 15 out of 54 survey respondents who identifed themselves as Green party voters fully agreed with the statement, and a further 8 agreed somewhat; taken together, more than the 20 who disagreed. Kuckartz & Rheingans-Heintze (2006) observe that "Mobility is of fundamental importance in [Germans'] lives .... the car .... symbolises freedom, well-being and prestige - the bigger, heavier and faster the better" (author's translation).

5.1.2 Demographic profile of survey respondents

Table 12 overleaf sets out the percentage of the sample (n = 400) who fall into each demographic category. Those percentages, or the corresponding ones for sub-populations such as those who have or want PV, will subsequently be used as the base for comparing the demographic profile of groups of survey respondents, for example those who rated return on investment highly as a reason for wanting to have a PV system. Survey respondents were also grouped into five bands by ERI, as in Table 11 below.

Environmental Responsibility Index of survey respondents		
	number	percentage
Very high (≥90% of maximum score, viz. 32.4–36)	81	20.3%
High (80 to <90% of max. score, 28.8 to <32.4)	67	16.8%
Medium high (70 to <80% of max., 25.2 to <28.8)	63	15.8%
Medium (60 to <70% of max., 21.6 to <25.2)	119	29.8%
Lower (<60% of max., ≤ 21.5)	70	17.5%

Table 11 : survey respondents (n = 400) grouped by Environmental Responsibility Index, calculated from responses to attitude statements, in bands high–low

	number	percentage			number	percentage
Politics				**Income range**		
CDU	55	13.8%		lower (≤€30k)	102	25.5%
CSU	42	10.5%		middle (€31-60k)	144	36.0%
FDP	22	5.5%		high (≥€61k)	80	20.0%
government parties	*119*	*29.8%*		withheld	74	18.5%
SPD	46	11.5%				
Greens	96	24.0%		**Family status**		
Die Linke	44	11.0%		in couple	270	67.5%
opposition parties	*186*	*46.5%*		*of whom female*	*59*	*52.8%*
others	24	6.0%		*of whom male*	*211*	*14.8%*
withheld	71	17.8%				
				single, male	84	21.0%
Educational level				single, female	46	11.5%
lower (≈GCSE)	204	51.0%				
middle (≈ A-level)	70	17.5%		with children	228	57.0%
higher (tertiary)	102	25.5%		no children	172	43.0%
other	24	6.0%				
				Gender		
Age band				male	295	73.7%
younger (≤34)	103	25.8%		female	105	26.3%
lower mid (35-44)	104	26.0%				
upper mid (45-54)	89	22.3%				
elder (≥55)	104	26.0%				

Table 12 : demographic profile of survey sample, by number of respondents and percentage of the total sample (n=400)

5.1.3 Why people in Germany want PV

Since the present thesis is concerned with the growth of household rooftop PV capacity in Germany, the primary focus of data analysis was on factors which may help explain why large numbers of people there have had PV systems installed, or wish to do so. Factors which may act as impediments to PV growth are of course also of interest, encompassing those which prevent the conversion of desire to have PV into actual installation, and those which deter people from wanting PV at all. They are considered in 5.1.8 below.

Of the 400 survey respondents, 192 fall into the group "have PV or will get it" and 155 into the group "want PV but prevented". Together they therefore constitute a population of 347 people in Germany who express a desire, whether fulfilled or not, to have a rooftop PV system. Those 347 people rated on a scale from 1 to 10 the importance of each of the eight possible reasons, listed in the survey, for wishing to have PV. The total and mean scores for each reason are set out in Table 13 below, in descending order. The mean was calculated as the total score for a given reason divided by the number of respondents who gave it a numerical rating, i.e. excluding those who answered "don't know/care", the number of whom is also given in the Table. It is assumed that those, relatively very few, who replied "don't know/care" would, so to speak, "join the consensus" and cluster around the mean score of those who gave one. Thus the calculated mean is taken to be valid for the whole population. Survey participants were also able to write in other reasons. 51 did, and their comments are briefly examined in 5.1.9 below. None gave a 1-10 rating to their additional reason(s), although the survey invited them to do so.

REASON	TOTAL SCORE	DON'T KNOWS	MEAN
Wish to contribute to combatting climate change	2349	6	**6.89**
Feed-in tariff makes a PV system financeable	2173	8	**6.41**
Desire for independence from the electricity utilities	2015	9	**5.96**
Want to have PV even if return on investment is low	1902	9	**5.63**
Feed-in tariff makes return on investment very attractive	1902	7	**5.59**
Feel it important to keep up with modern technology	1847	2	**5.35**
Influenced by neighbours/friends	1647	15	**4.96**
Inspired by a local initiative	1450	14	**4.35**

Table 13 : importance ratings of reasons for wishing to have a rooftop PV system (source: own fieldwork survey in Germany, n = 347) ; means calculated from total of respondents' ratings, excluding "don't know" replies.

Two tailed z-tests confirmed that the mean rating for "Feed-in tariff makes a PV system financeable" is significantly higher than that for "Feed-in tariff makes return on investment very attractive" : see Table 14 below.

Sub-group of survey respondents	n	'z'
Group 1: have a PV system or decided to get one	192	**2.35**
Group 2: want a PV system but unable to get	155	**0.96**
Groups 1 and 2 combined	347	**2.32**

Table 14 : z-test results comparing means of ratings by main sub-groups of survey respondents of financeability and of profitability as reasons for wanting PV

The mean rating for importance of financeability of PV, thanks to the feed-in tariff, is significantly higher than that for investment return, at the 2% confidence level ($z \geq 2.33$) for survey respondents who have or will get a PV system, and a whisker below that for all those who want PV even if unable to install it.

For the market segment of household rooftop systems, that supports the hypothesis stated in Chapter 2.1 : that the feed-in tariff primarily promotes installation of PV, not so much by providing a return on investment, as by making the installation feasible for individuals in terms of financing. For different categories of would-be PV system purchaser - such as households, farmers, small businesses, and professional investors - and indeed within those groups, the relative importance of financeability and profitability will vary (cf. the 'desire push-incentive pull space' postulated in 1.5 above). It is not claimed that, for households, return on investment is never a consideration. Rather, that the survey findings indicate that for them, statistically, financeability matters more than return.

The z-test does not require that the samples whose means are compared be normally distributed (e.g. Chalmers & Parker, 1989, p.64). It may nonetheless be instructive to examine the sample distributions, as in Figures 6, 7 and 8 below.

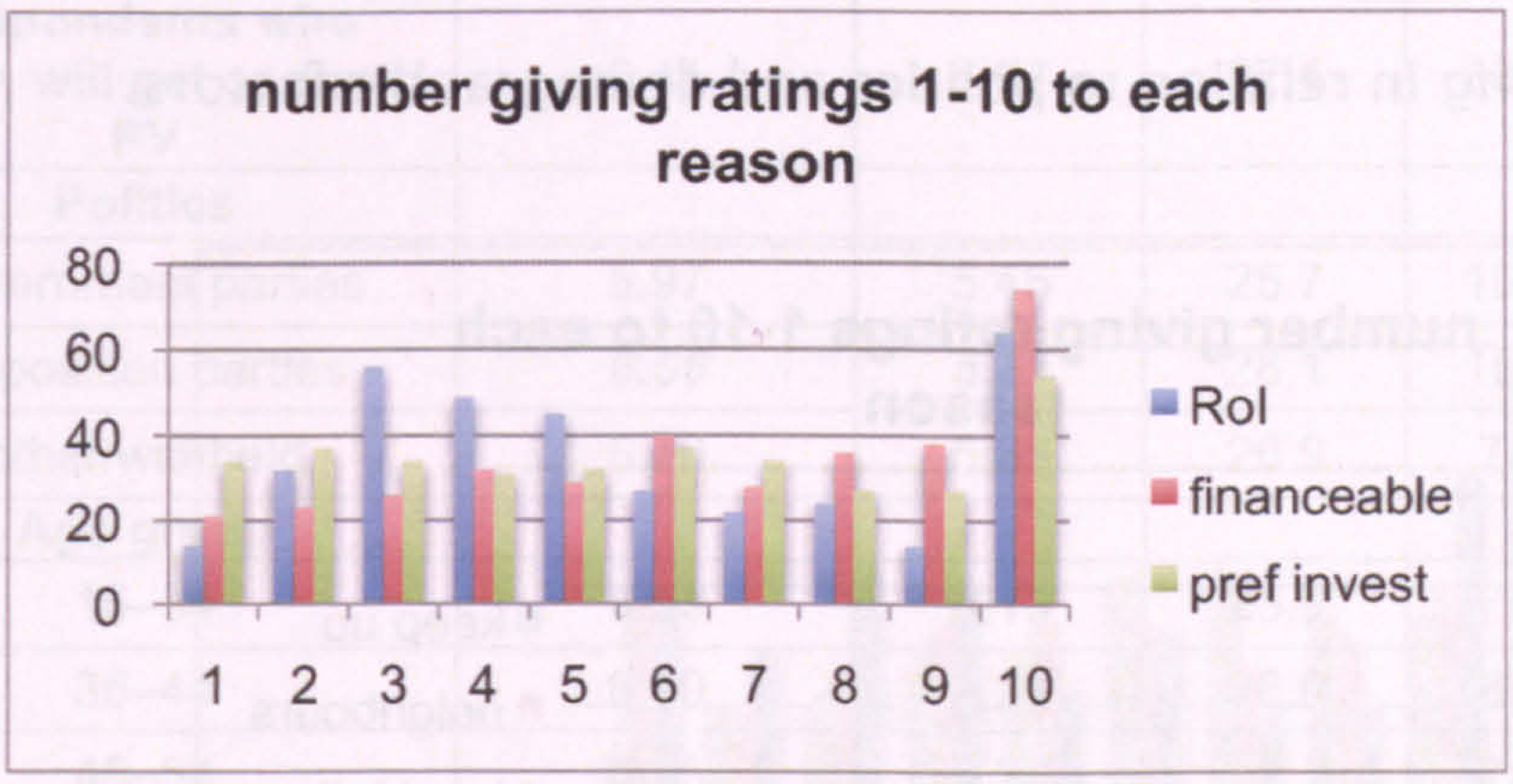


Figure 6 : number of respondents giving each importance rating (1–10) to finance related reasons for wanting a rooftop PV system (total n = 347). 'RoI' = feed-in tariff (FiT) makes return on investment in PV very attractive. 'Financeable' = FiT makes it feasible to finance a PV system. 'Pref invest' = prefer to invest in PV, even if the RoI is low.

The large number of maximum (10) ratings for the finance related reasons for wanting to install PV (Fig. 6) suggests that they are of great importance to many survey respondents. Around one third of respondents gave a rating of 8, 9 or 10. The proportion of 8-10 ratings is markedly higher (42.7%) for the 'financeable' reason than for either of 'attractive return' (29.4%) or 'prefer to invest in PV' (31.1%). That further supports the hypothesis that the feed-in tariff promotes growth of PV capacity by making it financeable, rather than lucratively profitable.

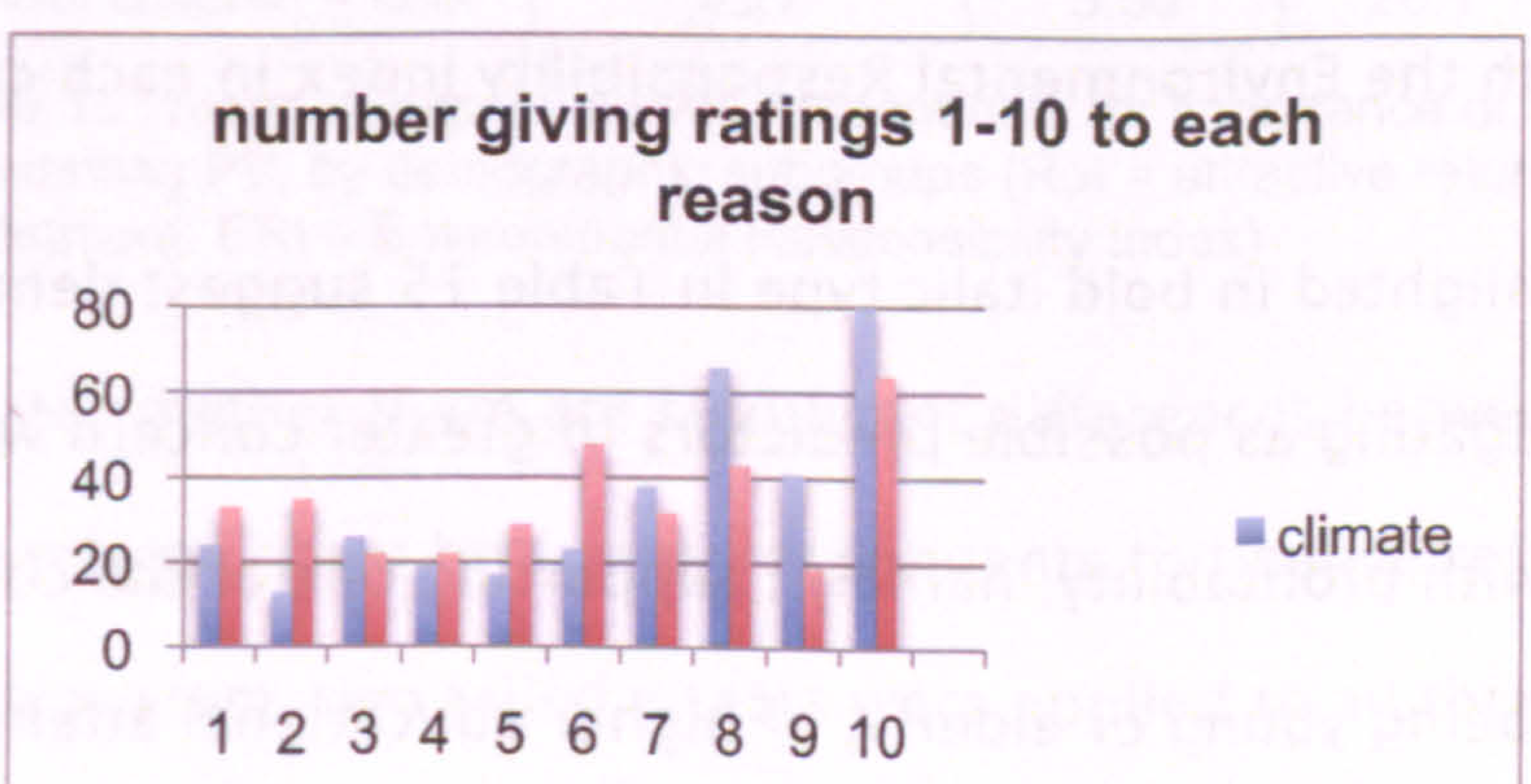


Figure 7 : number of respondents giving each importance rating (1–10) to principle related reasons for wanting a rooftop PV system (total n = 347). 'climate' = wish to help combat climate change; 'independence' = desire to be independent of electric utilities.

Ratings of 8-10 comprise a remarkable 59.7% of those for desire to help combat climate change, and a relatively lower 36.3% of those for desire for independence in electricity supply. For other ratings, the distribution appears to be inverse normal, which suggests scope for further investigation of the reasons for that pattern including in relation to politics and demographic factors.

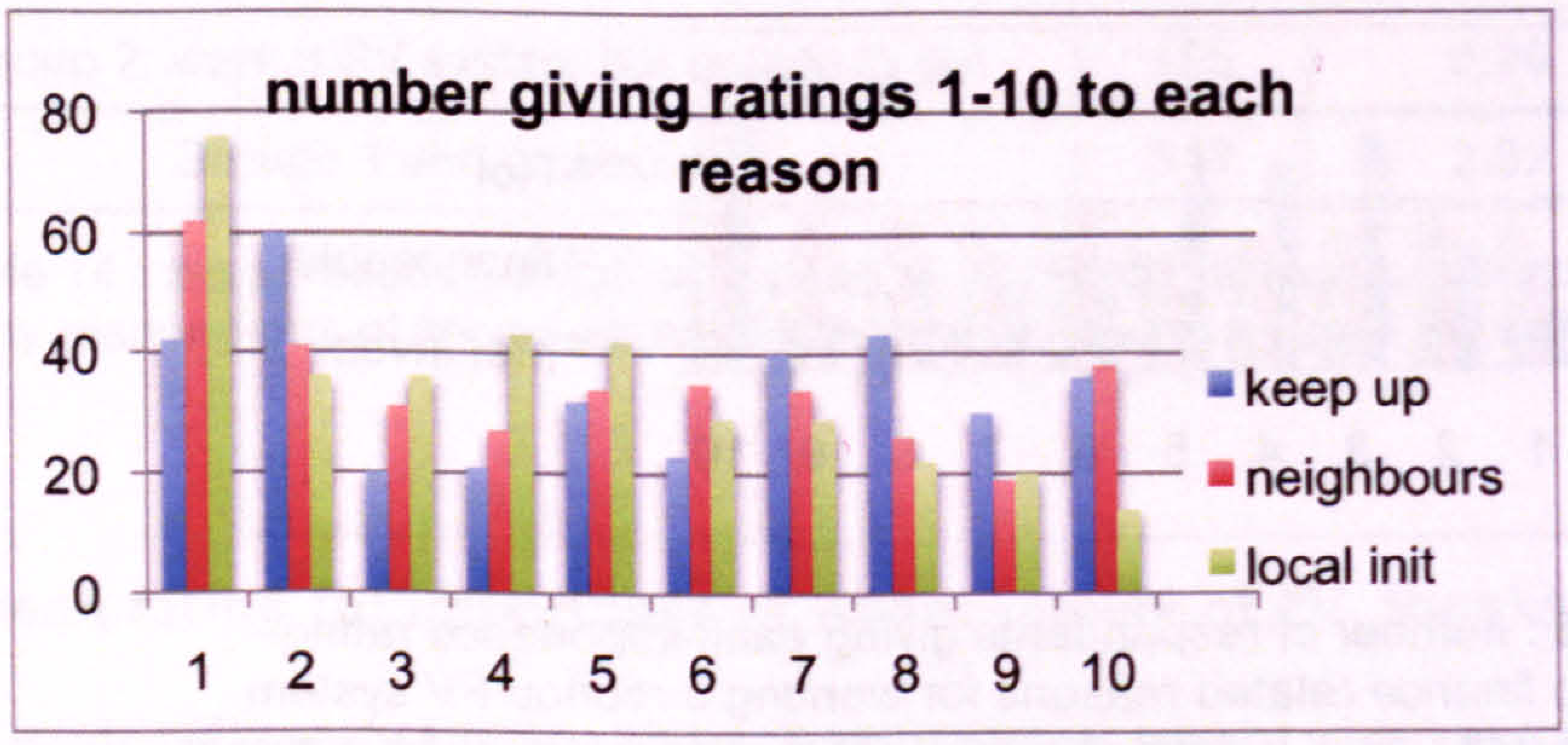


Figure 8 : number of respondents giving each importance rating (1–10) to influence related reasons for wanting a rooftop PV system (total n = 347). 'keep up' = important to keep up with modern technology; 'neighbours' = influence of neighbours/friends; 'local init' = inspired by local initiative.

Notable in Figure 8 is the preponderance of low ratings for these reasons for installing PV, which suggest that they are generally of lesser importance to survey respondents.

Table 15 overleaf shows the mean importance ratings given by those survey respondents who either have a PV system or want to get one (n=339) for 'Financeability' and for 'Return on investment' respectively, by demographic subgroup, along with the Environmental Responsibility Index in each case.

The differences highlighted in bold italic type in Table 15 suggest demographic factors worth investigating as possible predictors of greater concern with financeability than with profitability, namely : supporting one of the current opposition parties, being young or elderly, of higher educational attainment, lower income, and having children. However, nothing can reliably be inferred from the "income withheld" sub-group's mean ratings. Those with "other" educational qualifications *may* include people with a somewhat "alternative" lifestyle; but that is essentially speculation.

mean importance rating:	**Financeability**	**R o I**	**ERI**	**n**
respondents who have, will get or want PV	6.41	5.57	27.1	339
Politics				
government parties	5.97	5.45	25.7	103
opposition parties	***6.56***	***5.61***	28.1	162
other/withheld	6.70	5.65	26.9	74
Age group				
15–34	***6.59***	***5.13***	25.9	78
35–44	6.49	5.91	28.0	89
45–54	6.95	6.27	28.1	79
55 +	***5.72***	***5.03***	26.4	93
Educational level				
lower (GCSE equiv)	6.29	5.60	26.8	156
middle (A level equiv)	5.94	5.28	25.8	67
higher	***7.08***	***6.13***	29.3	97
other	***5.58***	***3.47***	22.5	19
Income band				
lower (≤ €30k)	***6.49***	***5.36***	26.8	74
middle (€ 31-60k)	6.25	5.60	27.4	130
high (≥ € 61k)	6.05	5.36	25.7	77
withheld	***7.14***	***6.06***	28.6	58
Family status				
in couple, with children	6.72	5.81	28.3	167
single, with children	5.53	4.78	25.5	38
in couple, no children	6.47	5.83	25.9	70
single, no children	6.05	5.14	26.3	64
with children – total	***6.50***	***5.14***	27.7	205
without children – total	6.27	5.50	26.1	134

Table 15 : mean ratings by survey respondents for importance of reasons for wanting PV, by demographic subgroups (RoI = attractive return on investment; ERI = Environmental Responsibility Index)

To investigate whether there are significant differences between the mean importance ratings given by survey respondents to finance related reasons for wanting a PV system, two tailed z-tests were applied to all three pairs of reasons: 'Financeability' vs 'Return on Investment' ("Fin - RoI"), 'Want to invest in PV even if RoI low' vs 'Return on Investment' ("Even if - RoI"), and 'Financeability' vs 'invest in PV even if RoI low' ("Fin - Even if"). The results are set out in Table 16 overleaf.

Comparison:	**Fin – RoI**			**Even if – RoI**			**Fin – Even if**	
	n	**z**		**n**	**z**		**n**	**z**
Whole sample	339	***2.35***		337	0.07		347	1.18
Politics								
govt parties	103	0.90		101	–0.11		104	0.56
opposition	161	1.84		161	0.46		167	0.52
other/withheld	75	1.21		74	–0.20		76	1.19
Age band								
15–34	78	1.48		76	0.25		80	0.93
35–44	89	0.60		89	–0.18		92	0.72
45–54	79	1.05		79	–0.32		80	0.71
55+	93	1.38		93	0.45		80	0.06
Educational level								
lower	156	1.37		154	0.01		162	0.72
middle	67	0.81		66	0.00		67	0.38
higher	97	1.75		98	0.09		67	0.56
Income range								
lower	74	1.30		73	–0.01		77	0.75
middle	130	1.43		130	0.03		131	0.52
higher	77	0.75		76	0.26		78	0.29
withheld	58	1.27		58	–0.18		61	0.99
Family status								
couple with children	167	***2.17***		167	–0.14		171	1.00
single with children	38	0.51		37	0.51		39	0.06
with children, total	*205*	**2.09**		*204*	*0.04*		*210*	*0.98*
couple, childless	70	1.09		70	–0.13		71	0.14
single, childless	64	0.72		63	0.27		66	0.19
childless total	*134*	*1.21*		*133*	*0.07*		*137*	*0.22*

Table 16 : results of two tailed z-tests for difference between pairs of finance related reasons for wanting PV, based on importance ratings given by survey respondents; 'z' scores in bold italic type are significant at the 5% ($z \geq 1.96$) or 2% ($z \geq 2.33$) level

It is apparent from the 'z' scores that there is no statistically significant difference between importance ratings for 'investment in PV even if the return is low' as compared with financeability as reasons for wanting PV; nor between those for financeability and for 'investment even if RoI low'.

On the other hand, some 'z' scores for the comparison of financeability with expectation of return on investment ("Fin - RoI ") point to a significant difference. For the whole population of those who have, will get or want to have a PV system (n=339), 'z' is 2.35 which indicates greater importance attached to financeability, at the 2% significance level (Chalmers & Parker, 1989, p.63). That supports the hypothesis H_1 (section 2.1). The 'z' scores of 2.09 for the demographic sub-group of survey respondents with children, and of 2.17 for the slightly smaller group of couples with children, are significant at the 5% level ($z \geq 1.96$). Two scores which are just short of that level suggest that political affiliation, namely supporting one of the current opposition parties, and higher (tertiary) educational level may also be predictors of greater concern with financeability than with profitability.

5.1.4 Reasons for wanting PV : possible correlations

Table 17 below presents the matrix of correlations (Pearson's r) between pairs of survey respondents' ratings on scale 1-10 of reasons for wanting PV, and between those ratings and the Environmental Responsibility Index calculated from respondents' replies to attitude statements.

	ERI	RoI	Finan-ceable	Invest anyway	Friends influence	Local init.	Keep up	Climate	Indep.
ERI	1	**0.29 6**	**0.296**	**0.265**	**-0.173**	**-0.146**	**0.395**	**0.326**	**0.160**
RoI	*n=340*	1	**0.616**	**0.194**	**0.008**	**-0.163**	**0.549**	**0.302**	**0.348**
Financ-eable	*n=339*	*336*	1	**0.301**	**-0.038**	**-0.124**	**0.413**	**0.413**	**0.345**
Invest anyway	*n=338*	*333*	*331*	1	**-0.053**	**-0.072**	**0.421**	**0.373**	**0.211**
Friends influence	*n=332*	*326*	*326*	*323*	1	**0.263**	**0.064**	**0.054**	**0.142**
Local init.	*n=333*	*327*	*327*	*326*	*326*	1	**-0.038**	**-0.069**	**-0.099**
Keep up	*n=345*	*339*	*338*	*337*	*332*	*332*	1	**0.252**	**0.311**
Climate	*n=341*	*335*	*334*	*333*	*327*	*328*	*340*	1	**0.264**
Indep	*n=338*	*332*	*331*	*330*	*329*	*328*	*338*	*334*	1

Table 17 : Correlation Matrix for ratings of reasons for wanting PV and Environmental Responsibility Index (ERI) calculated from responses to attitude statements, showing Pearson's r (upper right triangle) and size of sub-population (lower left triangle) within overall survey sample (n=400). Significances for $n \geq 100$: $p \leq 0.01$ for $r \geq 0.254$, $p \leq 0.02$ for $r \geq 0.230$.

Headings are compressed to fit into the available space. Expansions are: 'ERI' – Environmental Responsibility Index; 'RoI' – feed-in tariff (FiT) makes for attractive return on investment (RoI) in PV; 'Financeable' – FiT makes it feasible to finance a PV system; 'Invest anyway' – desire to invest in a PV system even if RoI is low; 'Friends influence' – influenced by friends/neighbours; 'Local init.' – inspired by a local initiative; 'Keep up' – wish to keep up with modern technology; 'Climate' – wish to contribute to combatting climate change; 'Indep.' – desire for independence from electricity utilities.

Since the sample size exceeds 100, any coefficient above 0.230 indicates a strong correlation with $p \leq 0.02$. That applies to just over half (19 out of 36) of the pairs. Of the remaining weaker or absent correlations, almost half (8 of 17) involve either 'influence of friends/neighbours' or 'inspired by local initiative', which correlate positively only with each other. Those are also the two reasons with the lowest mean ratings for importance, the largest proportion of lower (1-3 out of 10) ratings, and the most "don't know" replies, as shown in Table 13 in 5.1.3 above. This suggests that these reasons are relatively less strong as drivers for wanting PV; though clearly of importance to the roughly one fifth of respondents who rated them 8-10 out of 10.

Conversely, the highest coefficients were obtained for correlation of 'attractive return on investment' ('RoI') with 'financeability' ($r = 0.616$), and of 'RoI' with 'keep up with technology' ($r = 0.549$). The strong correlation of 'RoI' with 'financeability' does not, of course, necessarily indicate a causative link - simply that survey respondents tended to give high ratings to both reasons for wanting PV. A plausible interpretation is that those who rated both financeability and return on investment highly were both motivated to have PV installed because the feed-in tariff makes it feasible, and at the same time looking for *some* positive return on the investment. That is not inconsistent with the hypothesis that financeability is a significant factor, and that lucrative return on investment is not the only driver of desire to have a PV system. The constraints of the questionnaire format mean that the description of each reason to be rated was somewhat broad. A follow-up survey, perhaps combined with semi-structured interviews, could usefully investigate what constitutes an "attractive" return on investment for different persons.

Three pairs display a slightly less strong correlation ($r < 0.230$):

(a) Environmental Responsibility Index with 'Desire for independence from the electricity utilities' ($r = 0.160$) ;

(b) 'Wish to invest in PV even if return low' with 'Desire for independence from utilities' ($r = 0.211$) ; and

(c) 'Attractive return on investment' with 'Wish to invest in PV even if the return is low' ($r = 0.194$).

A possible explanation of correlation (a) is that persons who display a high level of environmental responsibility will tend to have concerns about fossil fuelled and nuclear power generation, associate that with the major electricity utilities, and therefore wish to become independent from them for electricity supply. The implication in that case is that they do not subscribe to a 'green' electricity tariff.

Correlation (b) is quite strong, $p < 0.005$ for $r = 0.195$ with ≥ 100 pairs, and seems unsurprising. Desire to have one's own electricity supply independent from the utilities should tend to encourage investment in a PV system, offsetting at least partially any concerns about level of return on the investment (RoI). That said, there is a stronger correlation ($r = 0.348$) between desire for independence and attractive return. Of those who rated independence more important than RoI, 141 of 328 (43%), a higher percentage than of the overall survey are educated to tertiary level (30.5% cf 25.5%) and have children (61.7% cf 57.0%), but a lower percentage support current opposition parties (41.1% cf 46.5%).

Correlation (c) is also quite strong, on the $p < 0.005$ threshold. At first sight it appears contradictory that persons looking for an attractive return should also be content with a low one. As indicated earlier, the issue here is what people consider an "attractive" return on investment in PV. The intended implication of the phrasing (verified by native speakers) in the survey questionnaire of this reason for wanting PV is that the return is higher than one would expect from e.g. a high street savings account: "Dank der Einspeisevergütung ist die Rendite wirklich attraktiv" - "Thanks to the feed-in tariff the return is really attractive".

That does not, however, exclude different interpretations by some respondents. It is conceivable, for instance, that someone keen on the idea of having a rooftop PV system would take the view that *any* positive return on the investment would be a bonus, possibly taking into account also the prospect of free PV electricity for a few years after the lifetime of the feed-in tariff, as it would mean getting the system in practice without net cost: it would pay for itself, plus a little extra.

5.1.5 Demographic factors affecting desire to have PV

Among replies to the environmental attitude statements (5.1.1 above), those who fully or partly agreed that "I am worried about what sort of world we will leave our children" constituted 75.4% of the 400 survey respondents. A fuller breakdown is in Table 18 below.

		Fully agree	Somewhat agree	Neither	Disagree
With children	n	117	57	37	16
	%	29.3%	14.3%	9.3%	4.0%
Without children	n	65	62	32	14
	%	16.3%	15.5%	8.0%	3.5%
Total %		*45.6%*	*29.8%*	*17.3%*	*7.5%*

Table 18 : breakdown of replies by survey respondents (n=400) to statement of concern about the sort of world being left to the next generation

These figures suggest that children represent a significant factor in the attitude of people in Germany to the environment, and therefore potentially also in their level of interest in installing PV. Further research would be needed to investigate why a substantial proportion of people who do not have children are nevertheless concerned about the next generation. It may be for instance that they plan to start a family, or that they care about relatives' or friends' children.

In the light of this, survey respondents' desire (or lack of it) to have PV was analysed with respect to their family status. The breakdown of the sample by family status is given in Table 19 below.

	with children	without children	*total*
in couple	180	90	*270*
single	48	82	*130*
total	*228*	*172*	*400*

Table 19 : family status of survey respondents ("in couple" includes marriage and other forms of cohabitation, e.g. civil partnership).

Figure 9 below shows the degree of desire to have a rooftop PV system installed, in terms of the percentage of each family status category who (a) already have a PV system or have decided to get one ("have or will"), (b) would like to have PV but are unable to ("want PV"), or (c) do not want PV ("don't want").

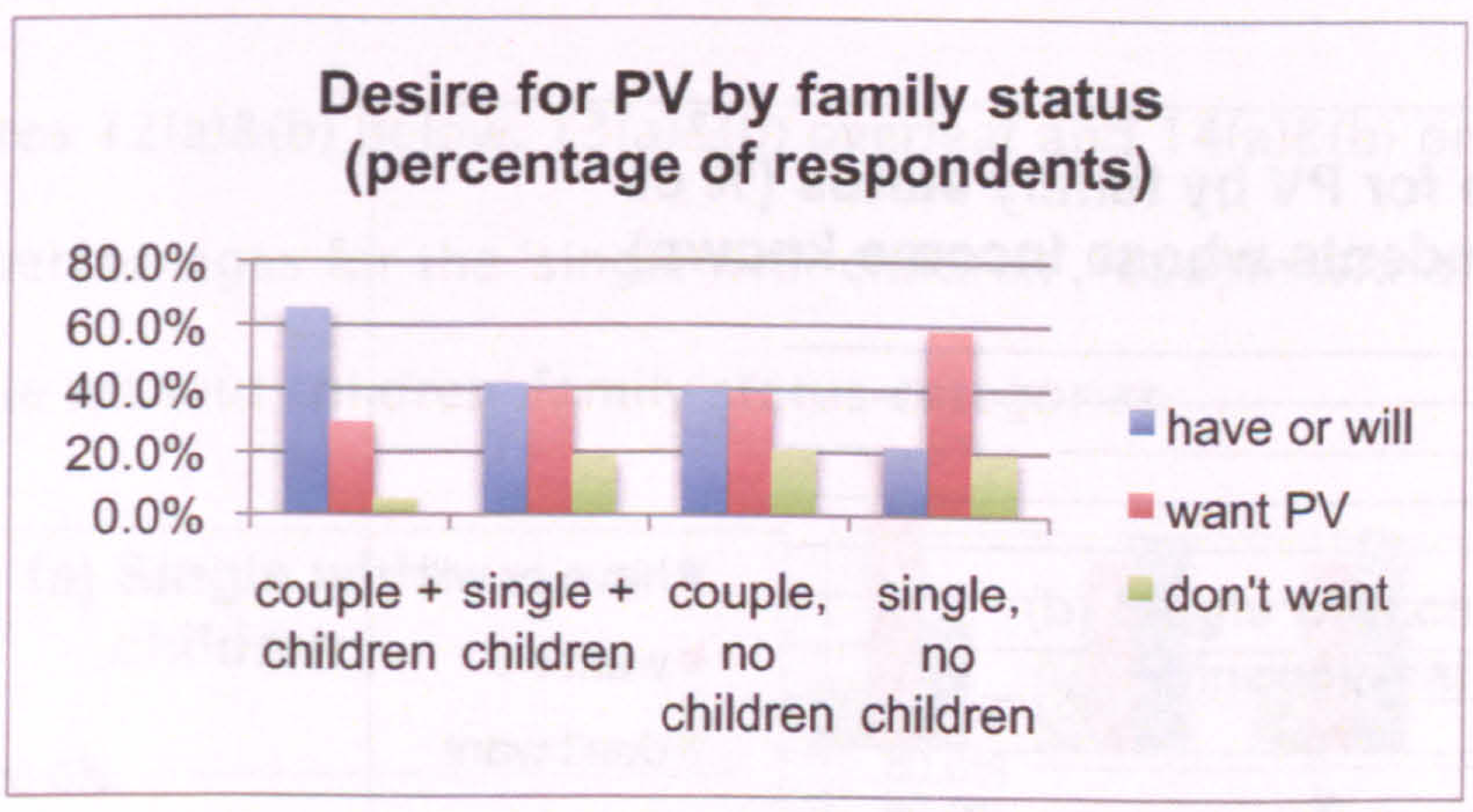


Figure 9 : percentage of respondents by family status category who have or will get a PV system, would like to have one but are unable to, or do not want one.

This indicates that couples with children are most likely to wish to have a PV system: 65.6% have or are getting one, a further 29.4% want one, total 95.0%. Single people with children are not far behind: 81.3% of them have, are getting or want PV. However, so do 78.9% of childless couples; and the split between 'have or will have' and 'want PV' is closely similar. The percentage of childless single persons in those two categories is also high, at 78.5%, but the 'want PV' group is nearly three times the 'have or will get' group.

Clearly it is necessary to incorporate other factors into analysis of the survey responses, with the aim of gaining a better understanding of what lies behind these broad brush findings. The first factor examined in this context was household income.

For clarity of presentation respondents were grouped into three income ranges: lower (up to €30,000 per annum), middle (€31-60,000), and high (over €61,000). The 74 respondents who declined to disclose their household income were excluded, leaving 326 responses: 145 married with children, 77 married without children, 45 single with children, 59 single without children. As Figure 10 below shows, their profile of desire for PV according to family status closely resembles that of the full survey response (n = 400) in Figure 9 on the preceding page.

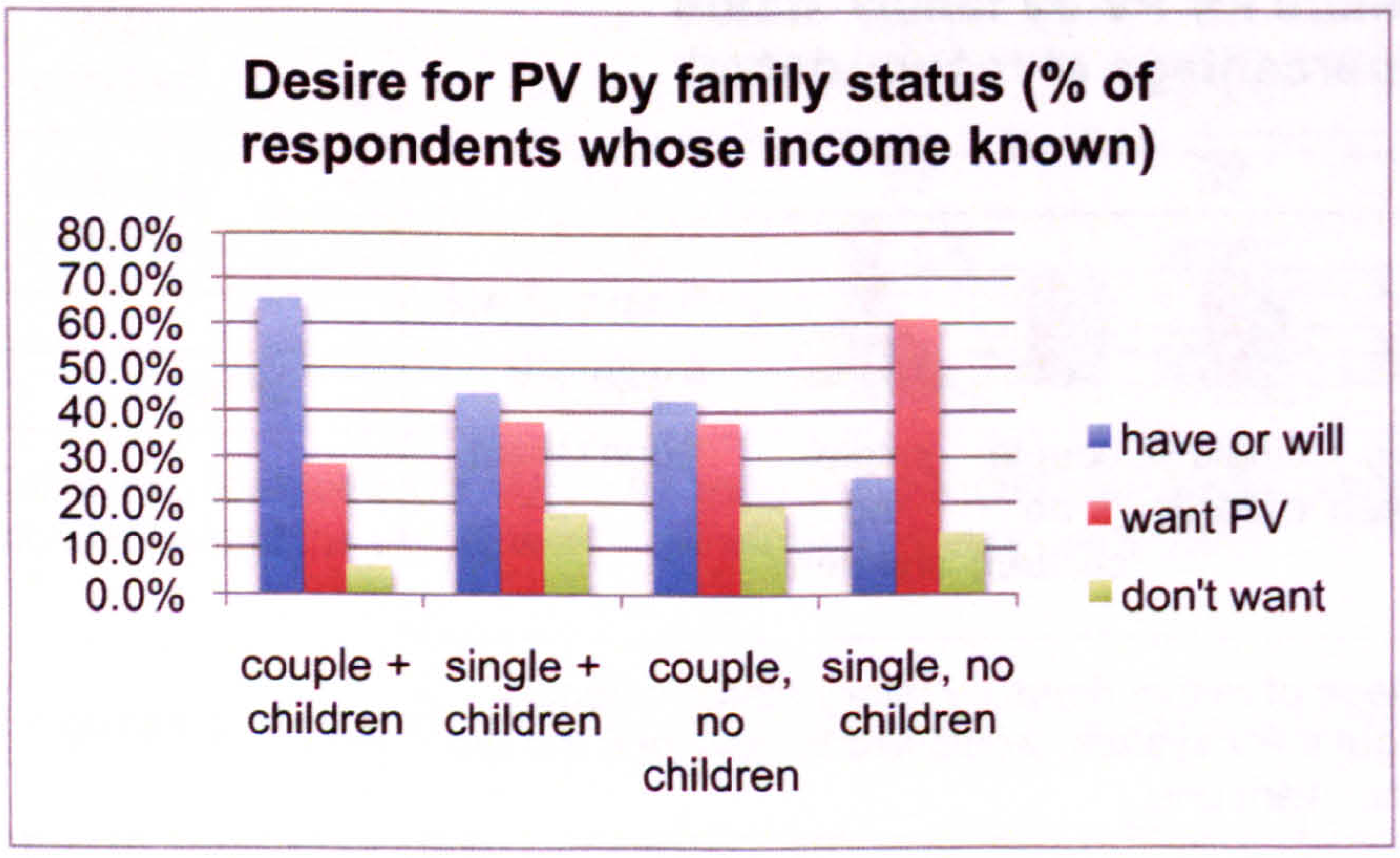
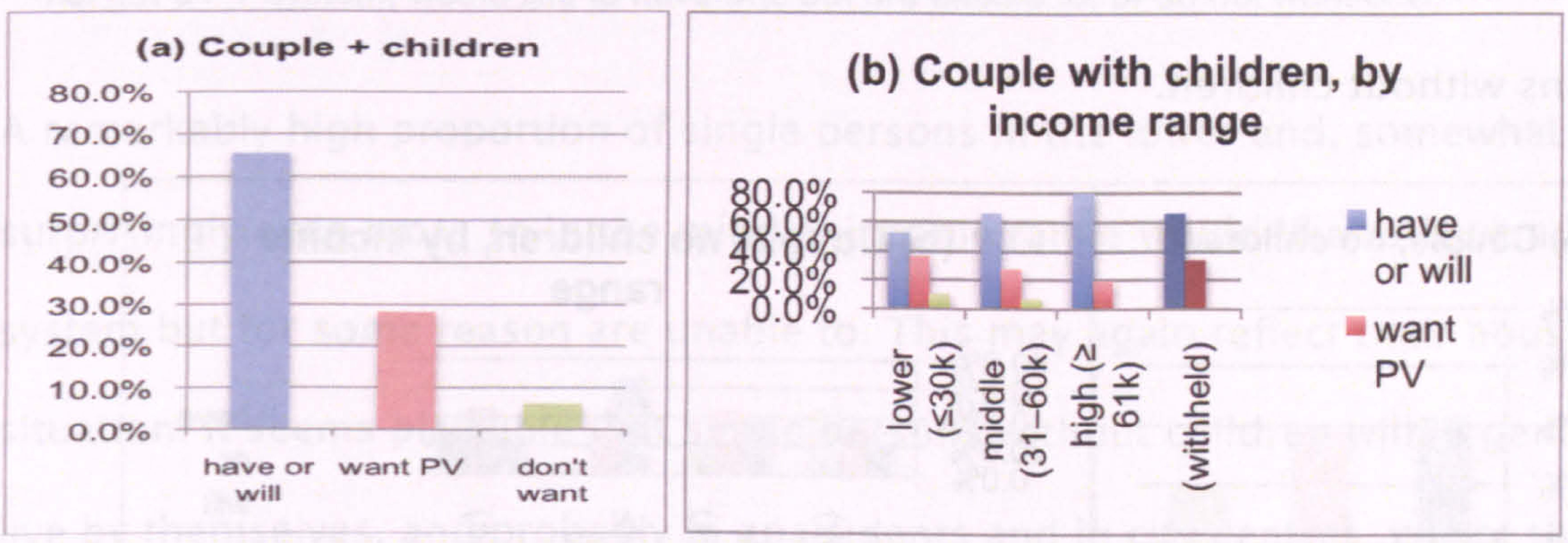


Figure 10 : percentage of respondents by family status category, who disclosed their household income (n = 326), who have or will get a PV system, would like to have one but are unable to, or do not want one.

The proportion of couples with children who have or will get a PV system increases with income level, as Figures 11(a)&(b) overleaf illustrate. (Fig. 11(a) repeats for convenience the overall percentages for this family status category, from Figure 10 above.) Fig. 11(b) includes the percentages for the 35 respondents in this family status category who withheld their income; it is reassuring that they quite closely resemble those for the "couple with children" group in the full survey response, indicating that the smaller number of responses are still representative.

It is noteworthy that *all* those in the high income range either already have or are getting PV (80.6%), or would like to have it (19.4%).



Figures 11 (a)&(b): percentage of respondents in a couple with children (a) in full survey response (n = 180), and (b) who disclosed their household income (n = 145), who have or will get a PV system, would like to have one but are unable to, or do not want one.

Figures 12(a)&(b) below, 13(a)&(b) overleaf and 14(a)&(b) on p.157 likewise show the percentages for the 'single with children', 'couple without children', and 'single without children' family status categories.

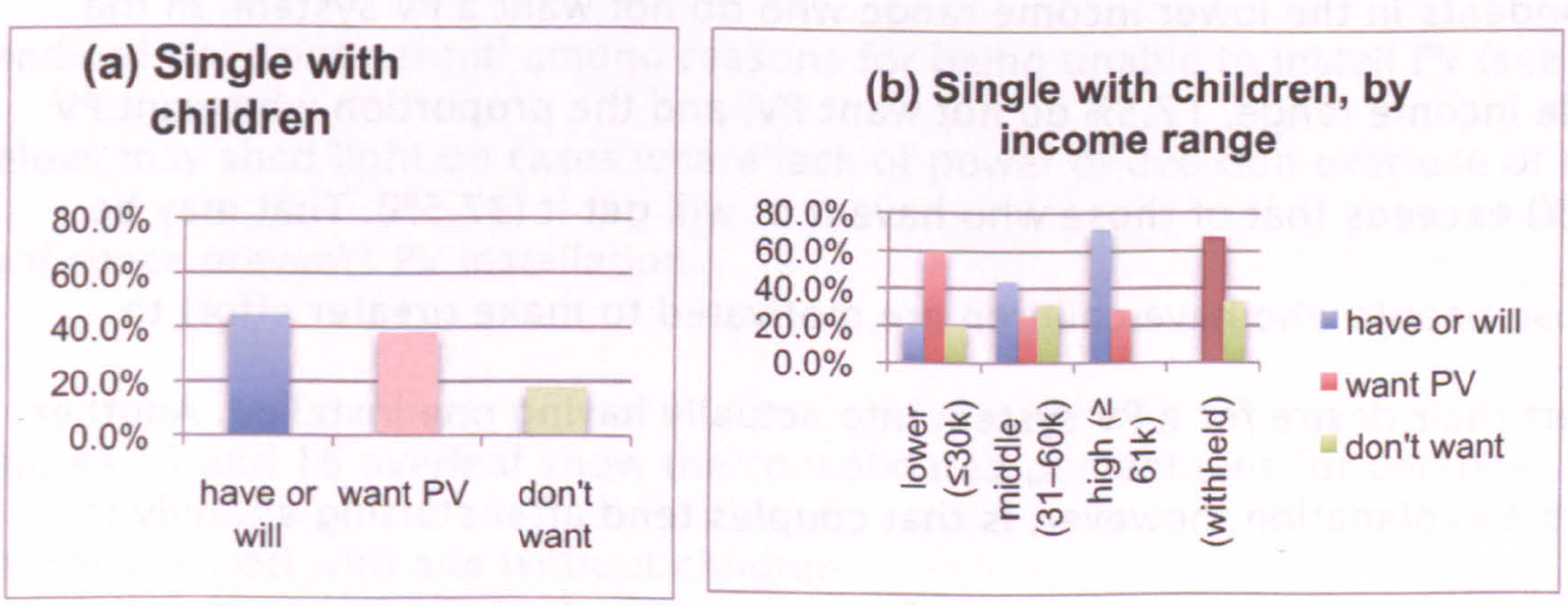


Figure 12(a)&(b): percentage of respondents single with children (a) in full survey response (n = 48), and (b) who disclosed their household income (n = 45), who have or will get a PV system, would like to have one but are unable to, or do not want one.

In the 'single with children' category, the proportions of respondents who have or will get PV, or who would like it, are generally similar to the 'couple with children' category but with different splits between 'have or will' and 'want PV', most notably for the lower income range. The proportion who do not want PV is markedly higher in the lower and middle income ranges. As in the case of couples with children, *all* those in the high income range either have or will get PV (71.4%) or would like it (28.6%).

The corresponding Figures 13(a)&(b) below show the rather different pattern for couples without children, and 14(a)&(b) overleaf the very different one for single persons without children.

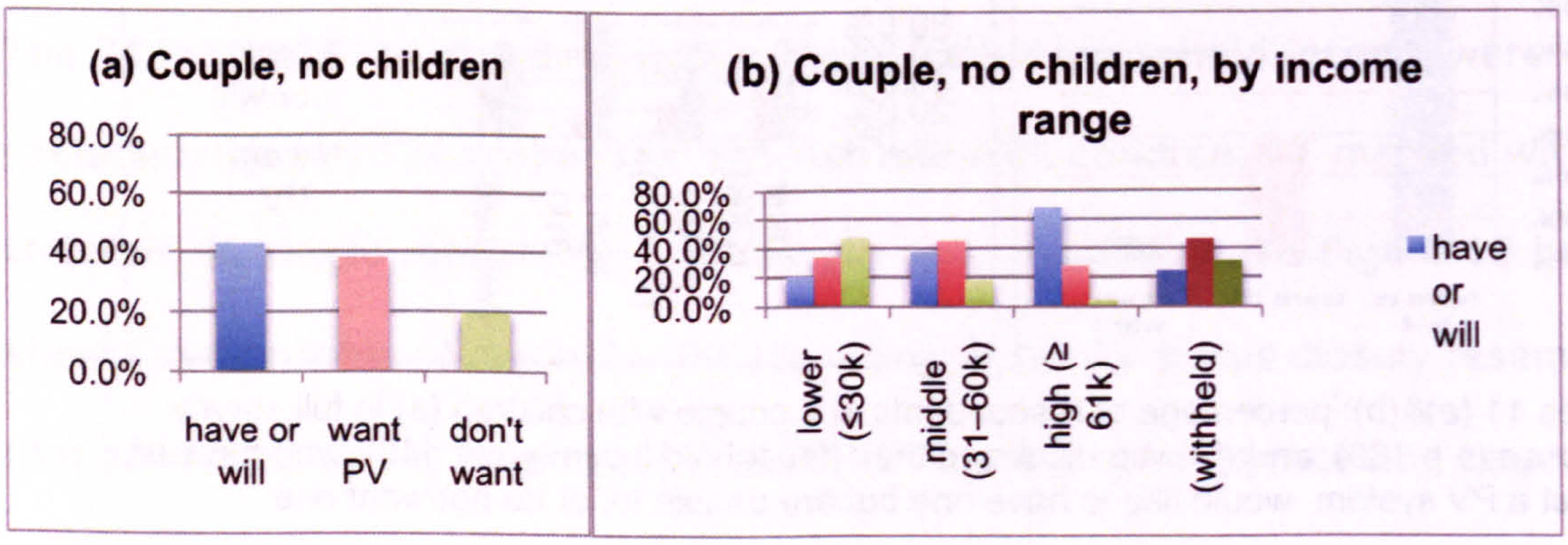


Figure 13(a)&(b): percentage of couples without children (a) in full survey response (n=90), and (b) who disclosed their household income (n = 77), who have or will get a PV system, would like to have one but are unable to, or do not want one.

The striking feature of this category is the high proportion (46.7%) of respondents in the lower income range who do not want a PV system. In the middle income range, 17.5% do not want PV, and the proportion who want PV (45.0%) exceeds that of those who have it or will get it (37.5%). That may be because people who have children are motivated to make greater effort to convert their desire for a PV system into actually having one installed. Another possible explanation, however, is that couples tend after starting a family to move into larger dwellings, so that the percentage who have power of decision over use of the roof increases (house rather than apartment, for instance), making PV installation possible.

Figure 14(a)&(b): percentage of respondents single without children (a) in full survey response (n = 82), and (b) who disclosed their household income (n = 59), who have or will get a PV system, would like to have one but are unable to, or do not want one.

A remarkably high proportion of single persons in the lower and, somewhat surprisingly even more so in the middle, income range would like to have a PV system but for some reason are unable to. This may again reflect their housing situation: it seems plausible that single persons without children will in general live by themselves, and probably in apartments and in city centres, where they do not have sole power of decision over use of the roof space. According to Seifried & Witzel (2010), roughly one half of German people do not own their own home, and even approximately 20% of owner occupiers live in apartment blocks with shared roof space, on which it is not possible to install PV without the consent of all the owners in the block, which is often difficult to obtain. The ratings given for 'landlord does not permit' among reasons for being unable to install PV (see 5.1.8 below) may shed light on cases where lack of power of decision over use of the roof space prevents PV installation.

Figures 15 and 16 overleaf show the consolidated percentages for persons (married or not) with and without children.

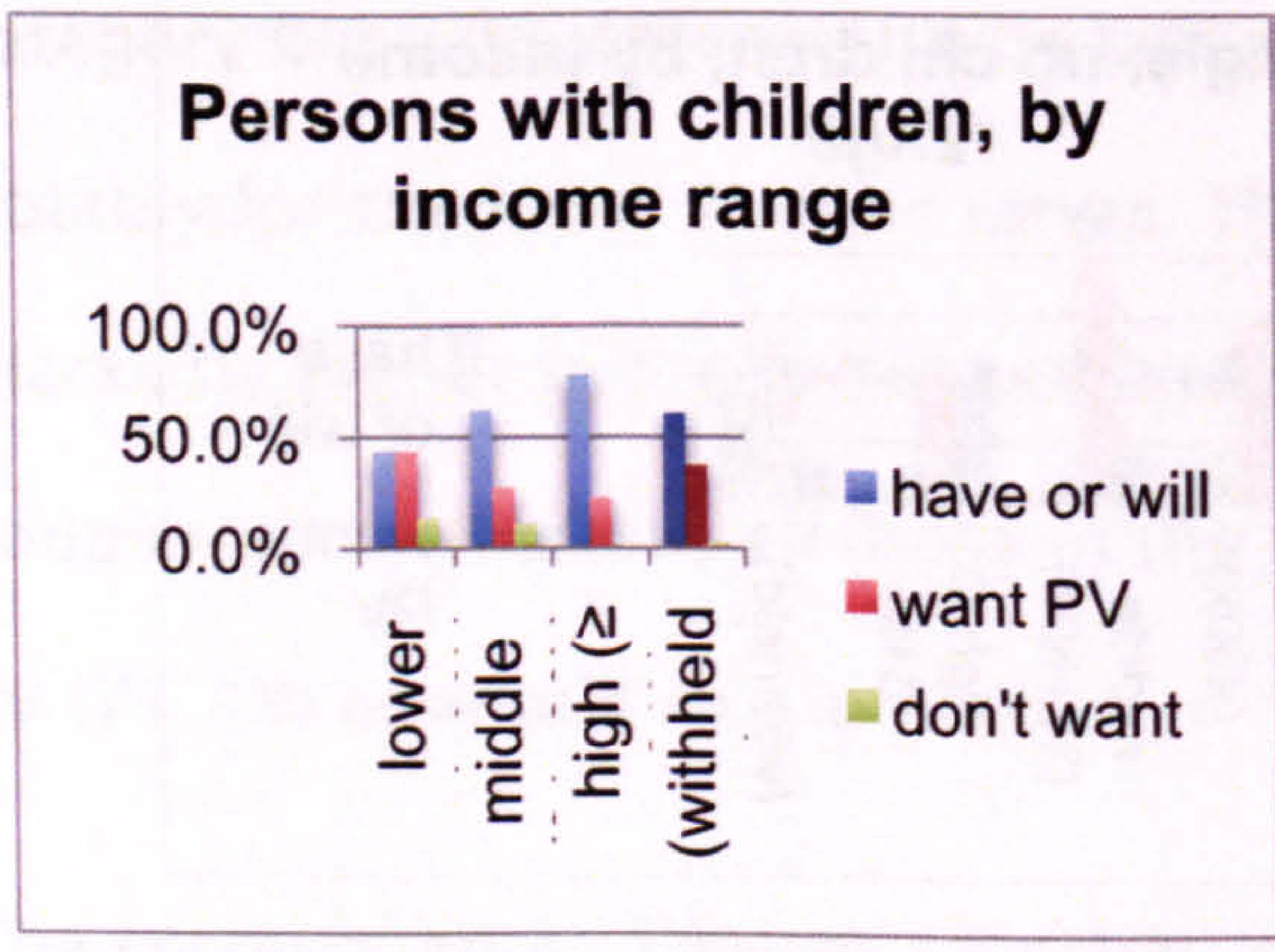


Figure 15: percentage of respondents with children who disclosed their household income (n = 190) or withheld it (n=38), who have or will get a PV system, want one but are unable to get, or do not want one.

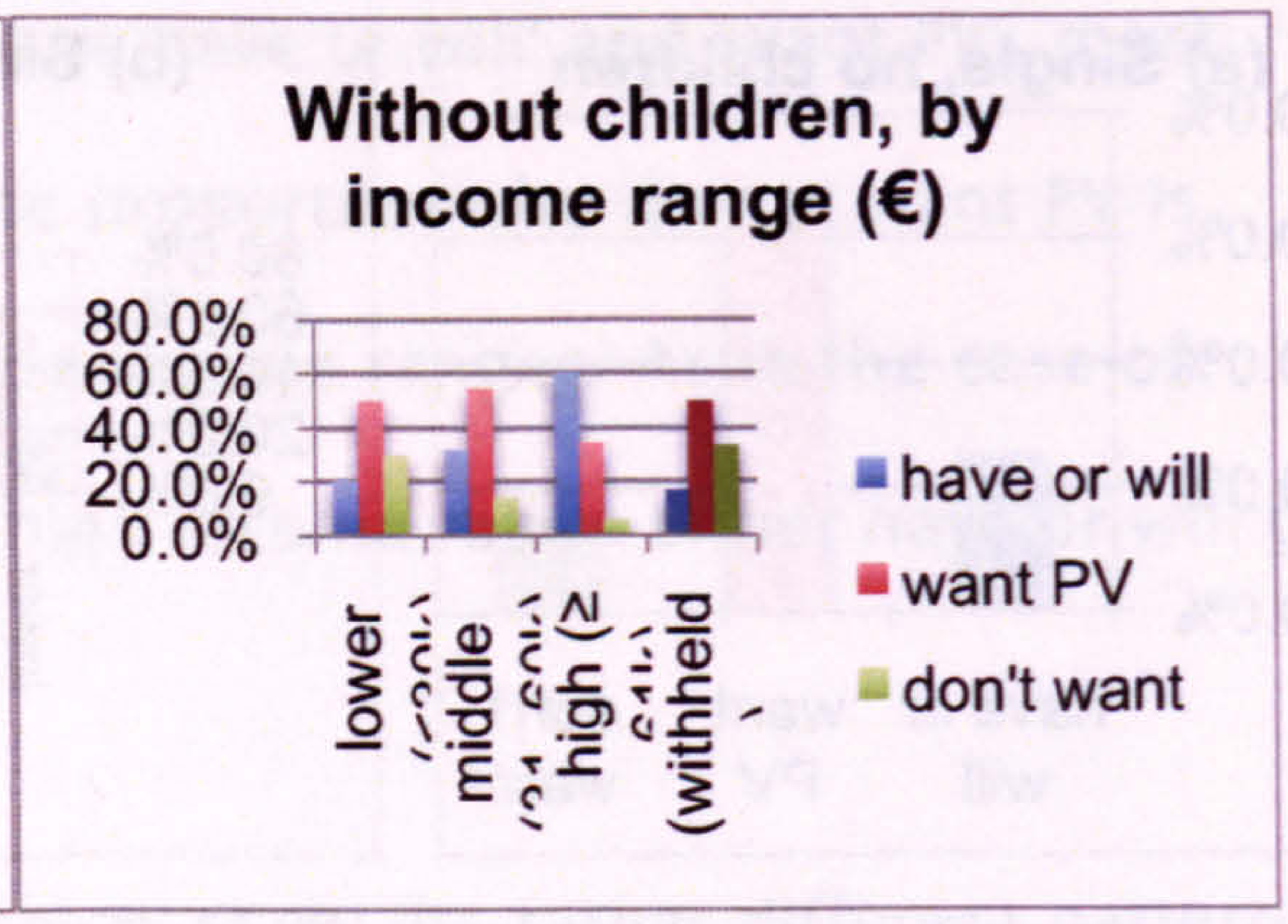


Figure 16: percentage of respondents without children who disclosed their household income (n=136) or withheld it (n=36), who have or will get a PV system, want one but are unable to get it, or do not want one.

A comparison of Figures 15 and 16 indicates that having children increases both the desire to have a PV system (red + blue columns) and, especially, the conversion of that desire into actual installation (blue column), which is also boosted by higher household income. The combined percentages of those who either have PV or will get it, and those who would like to have it, by income range are set out in Table 20.

Income range	lower	middle	high
Children	86.8%	89.2%	100%
No children	70.5%	86.0%	94.3%

Table 20 : percentage of survey respondents who disclosed income (n = 326),who have/will get a PV system or wish to have one, according to their income range and whether they have children.

5.1.6 Conclusions in relation to demographics

The foregoing findings suggest that level of income affects the likelihood that a household will get a PV system installed. The picture with regard to desire to have a PV system is more mixed, with a higher proportion of respondents without children desiring a PV system but unable to get one; and a substantial percentage not wanting PV at all, especially in the lower income range.

The reasons for these patterns are, however, are not necessarily to do with being unable to *afford* PV, since in principle the feed-in tariff mechanism makes it financeable for anyone - in line with the central hypothesis of this thesis. There may be an indirect causal link via age cohort and type of dwelling, with higher income (possibly thereby also more settled) families more likely to be in their own house, and thus able to authorise PV installation on the roof. Lack of landlord's consent is among the reasons for not being able to install PV considered in 5.1.8 below.

5.1.7 Who put financeability above profitability?

As a simplified form of multivariate analysis, the profiles were examined of those survey respondents who rated 'feed-in tariff makes it feasible to finance a PV system' as more important than 'feed-in tariff makes return on investment attractive', and vice versa. Gender was discounted, as the approximately 3:1 ratio of male to female respondents indicates that in many cases the male replied for the household, even though the survey invited separate individual views. The Environmental Responsibility Index was included, with demographic factors.

Table 21 overleaf sets out the profile of survey respondents who have, are getting or want to have PV, in relation to demographic factors and ERI. The percentages in Table 21 relate to the sub-population among the full survey (n=400) who have a PV system, have decided to get one, or wish to have one, and who gave importance ratings to 'attractive return on investment' and to 'makes it feasible to finance' as reasons for wanting PV (i.e. excluding "don't know" replies), a total of 337. Of those, 169 rated 'financeable' above 'return on investment (RoI)'; while 84 rated 'RoI' above 'financeable' ; and 94 gave them equal ratings.

factor	Population	rated RoI > Fin	rated Fin > RoI	rated Fin >>
n	*337*	*84*	*169*	*85*
Politics				
Government	29.9%	32.1%	29.0%	20.0%
Opposition	47.8%	45.2%	46.7%	52.9%
other/withheld	21.9%	22.7%	24.3%	27.1%
Income range				
lower (≤€30k)	21.7%	22.6%	22.5%	24.7%
middle (€31-60k)	38.6%	34.5%	31.4%	32.9%
high (≥€61k)	22.6%	21.4%	26.6%	21.2%
withheld	17.2%	21.4%	19.5%	21.2%
Age band				
younger, 15-34	22.6%	19.0%	27.8%	29.4%
low mid, 35-44	26.4%	31.0%	26.0%	24.7%
upper mid, 45-54	23.4%	22.6%	17.2%	22.4%
elder, ≥55	27.6%	27.4%	29.0%	23.5%
Education				
lower (≈GCSE)	51.0%	50.0%	43.2%	42.4%
middle (≈A level)	17.5%	21.4%	17.8%	17.6%
higher	29.1%	25.0%	30.2%	30.6%
other	5.6%	3.6%	8.9%	9.4%
Family status				
couple	70.3%	63.1%	66.9%	67.1%
single	29.7%	36.9%	33.1%	32.9%
children	60.5%	60.7%	60.4%	63.5%
no children	39.5%	39.3%	39.6%	36.5%
ERI				
very high	23.1%	17.9%	20.7%	20.0%
high	17.5%	13.1%	14.2%	15.3%
medium high	15.4%	17.9%	14.8%	15.3%
medium	27.0%	40.5%	27.2%	27.1%
lower	16.9%	10.7%	23.1%	22.4%

Table 21 : percentage of survey respondents by demographic factor and by Environmental Responsibility Index (ERI), among those who have, will get or want PV (n=337), who rated 'attractive return on investment' (RoI) above 'feasible to finance PV' (Fin), 'Fin' above 'RoI', and 'Fin' by 3 or more points above 'RoI' on scale 1–10, respectively.

From inspection of Table 21 , there are a number of candidates for predictors of greater concern with, respectively, return on investment from, or financeability of, a PV system.

A <u>higher</u> percentage than in the sub-population of those who rated 'RoI' above 'financeable' support parties in the current governing coalition (CDU, CSU, FDP), are in the 35-44 age band, are educated to A-level equivalent, are single, and have a medium (60-70% of maximum) score on the Environmental Responsibility

Index (ERI). A lower percentage are in the middle income range, received higher education, are in a couple, and scored highly on the ERI.

Among those who rated 'financeable' as more important than 'RoI', a higher percentage than in the sub-population are in the higher income range, the younger age band, are single, and scored low on ERI. A lower percentage are in the middle income range, the 35-44 and 45-54 age bands, were educated only to GCSE equivalent, are in a couple, and scored highly on ERI.

Some markedly larger variances are apparent from inspection of the percentages for those who rated 'financeability' as more important than 'RoI' by at least 3 points on the 1-10 scale. This group is half the size of the overall 'financeability' > 'RoI' group (n = 85, out of 169), but almost the same size as the 'RoI' > 'financeability' group (n = 84). Supporters of government parties make up only 20.0% against 29.9% of all those who have or want PV; 29.4% vs 22.6% are in the 15-34 age band, and 32.9% vs 38.6% in the middle income range; 22.4% vs 28.2% were educated to A-level equivalent. An intriguing variance is that 9.4% of the 'financeability' >> 'RoI' group, compared with 5.6% of the wider 'have or want PV' population, declared their level of educational qualification to be "other". One could speculate as to the nature of their qualifications - e.g. trade Master, music, art? - but it would require further research to investigate the details.

Notwithstanding such tantalising indications, however, chi-squared tests found no significant differences between the sub-groups who rated financeability as more important than attractive return on investment or vice versa, in terms of demographic factors: see Table 22 overleaf.

sub-group / factor	RoI > Fin		Fin > RoI		Fin >> RoI	
	χ^2	signif.	χ^2	signif.	χ^2	signif.
Politics	0.224	90%	0.247	90%	0.831	70%
Income	1.021	80%	2.773	50%	1.508	70%
Age band	0.907	90%	3.453	40%	1.864	70%
Education	1.573	70%	2.196	60%	2.425	50%
Couple/single	1.640	20%	0.636	50%	0.343	60%
Children/not	0.001	95%	0.004	95%	0.256	70%
ERI	5.998	20%	3.341	40%	1.613	85%

Table 22 : results of chi-squared tests for difference in demographic profile between sub-groups who rated attractive return on investment as more important than financeability (RoI>Fin) or vice versa (Fin>RoI, Fin>>RoI); 'signif.' = probability that difference in profile could arise by chance (taking into account number of degrees of freedom)

Some of the variances in demographic factors apply to both, in theory opposite, groups: a higher percentage are single and with lower ERI score; a lower percentage in middle income band, in a couple, or with high ERI score. That suggests that those factors may not be reliable predictors of preference for RoI over financeability or vice versa. A further note of caution is that the high percentages of those who withheld their political affiliation or income range impact upon the reliability of either of those factors as a predictor of variance.

5.1.8 : Reasons for *not* installing PV

Of 400 survey respondents, 155 stated that they either cannot or do not wish to have PV installed on their roof. Their ratings of the importance of various reasons are set out in Table 23 overleaf.

(n = 155)	Total score	Mean	standard deviation (Excel)
buying into communal PV	801	5.17	3.05
reluctant to take on large/long term loan	768	4.95	3.11
lack of funds	760	4.90	3.02
waiting for lower prices	748	4.83	3.13
landlord won't permit	752	4.85	3.73
roof not suitable	676	4.36	2.78
insolation too low	584	3.77	2.99
hassle, bureaucracy	614	3.96	2.79
too complex	613	3.95	3.05

Table 23 : survey respondents' (n=155) ratings of importance of reasons for being unable or not wishing to have PV installed.

Several points of interest may be noted from an initial examination of these figures. The reasons for not installing PV fall into three groups, relating to:

(a) finance - reluctance to take on a large/long term loan, lack of funds, waiting for lower PV system prices

(b) circumstances - landlord will not permit PV installation, roof is not suitable (e.g. faces north, overshadowed), insolation is too low

(c) complexity - hassle and bureaucracy e.g. in arranging finance/installation, PV as a subject too complex to understand.

The finance-related reasons are generally speaking rated as more important, though not by a large margin. The remaining reason, 'buying into communal PV', means that the respondent has decided to purchase a share of a (usually large) PV array on a communal building such as a school, instead of having a PV system installed on his or her own dwelling roof. Possible grounds for that decision could be in any of the groups (a)-(c) above.

For example, in 'finance' possible grounds are that the respondent has sufficient money available to buy a small share (say 2 kWp) of a communal array, but not enough for a system on his or her own roof. In that case one would expect the ratings for 'buying into communal array' and 'lack of funds' to correlate. As Table 24 below shows, however, the Pearson's correlation of 0.158 falls just short of the 10% significance level (0.164).

Alternatively, the grounds may be in 'circumstances' because the dwelling roof is not suitable or not available, and a share in a communal array allows the respondent to participate in PV growth and feed-in tariff income. That could well reveal itself in a correlation between 'buying into communal PV' and e.g. 'roof not suitable'. Again, however, any correlation is weak (0.114). Then again, the respondent may be deterred by the perceived complexity of the technology or the effort involved in arranging a dwelling rooftop installation, and opt for the relative simplicity of putting money into a communal array where others do the work. One would then look for correlation between 'buying into communal PV' and e.g. 'too complex'. In this case there is a correlation (0.167) albeit only at the 10% significance level.

	Comm -unal	Loan concern	Lack of funds	Await price fall	Landlord obects	Bureauc.	Comple x	Roof not suitable	Insolation low
Invest in communal PV	1	***0.250***	0.158	0.041	-0.130	***0.295***	0.167	0.114	0.088
Reluctant to take on loan		1	***0.256***	***0.426***	-0.066	***0.368***	***0.251***	0.118	0.244
Lack of funds			1	***0.311***	-0.045	0.172	0.088	0.005	0.105
Awaiting lower prices				1	-0.080	***0.365***	0.242	-0.012	***0.337***
Landlord objects					1	-0.164	-0.143	0.178	0.027
Bureaucracy						1	***0.320***	0.055	0.410
Complexity							1	0.095	***0.284***
Roof not suitable								1	0.096
Insolation too low									1
Significance (n > 100)	*10%*	*0.164*	*5%*	*0.195*	*2%*	*0.230*	*1%*	*0.254*	

Table 24 : correlation matrix for importance of reasons for not getting PV installed; Pearson's coefficient, results in bold italic type are significant at 2% level (p=0.02) or better

Many of the correlations indicated in Table 24 intuitively make sense, such as 'bureaucracy' with 'complexity', and 'reluctance to take on loan' with 'lack of funds' and 'awaiting lower prices' (not quite as yet enough money disposable to install PV, but do not want to borrow). Some are puzzling and may be spurious, in particular 'awaiting lower prices' with 'bureaucracy' (unless the bureaucracy is involved in a loan application?), and 'complexity' with 'low insolation' (creating a need for a more complex technical solution?).

5.1.9 Other reasons

Among the 400 survey respondents, 51 wrote in other reasons for wanting a PV system. Two recurring themes, with ten or more entries, were:

- desire to contribute to climate and environmental protection
- dislike of the major electricity companies, hence desire to generate own electricity and contribute to transformation of the supply system.

Other reasons that 3 or more respondents gave were: for the sake of the children; opposition to nuclear and coal power generation; visual appeal of a PV system, interest in the technology; and to earn money, including as a future supplement to pension.

5.1.10 Shortcomings

With hindsight, it might have been better also to ask in the survey questionnaire for the year of installation of PV systems, along with their size. That could have made it possible to pick up any shift in motivation to install PV, for instance in relation to the system price fall of the last two years, and in particular the temporary mismatch between price and feed-in tariff rate in the first half of 2010.

It is, however, considered a reasonable assumption that for most of the period of rapid growth in PV capacity installed in Germany, that is from 2007 to date, system prices and feed-in tariff rates were sufficiently in balance that expected return on investment remained stable within quite narrow limits. The scope of and time available for the present research did not permit a more detailed analysis of "Solar League" data, to establish the new capacity added each year and to identify any year on year trends in capacity growth vs expected return on investment.

5.2 Sensitivity analysis of expected return on investment

5.2.1 Introduction

If a substantial proportion of PV capacity has been installed in parts of Germany where the expected return on investment is relatively low, by comparison with a 'high street' savings account, that will tend to support the hypothesis that profitability is not the sole, or even the main, driver of desire to install PV. The comparison assumes that the same sum of money as invested in the PV system would otherwise be placed in a savings account or other investment vehicle, or series of them, for the same period of time. That may be somewhat artificial, but comparison would not otherwise be practicable. The question of people's willingness to commit money in one or another kind of investment over long periods is worthy of separate exploration.

Following are the results of the tests described in 4.1.8 above, also presented in Plater & Boyle (2009).

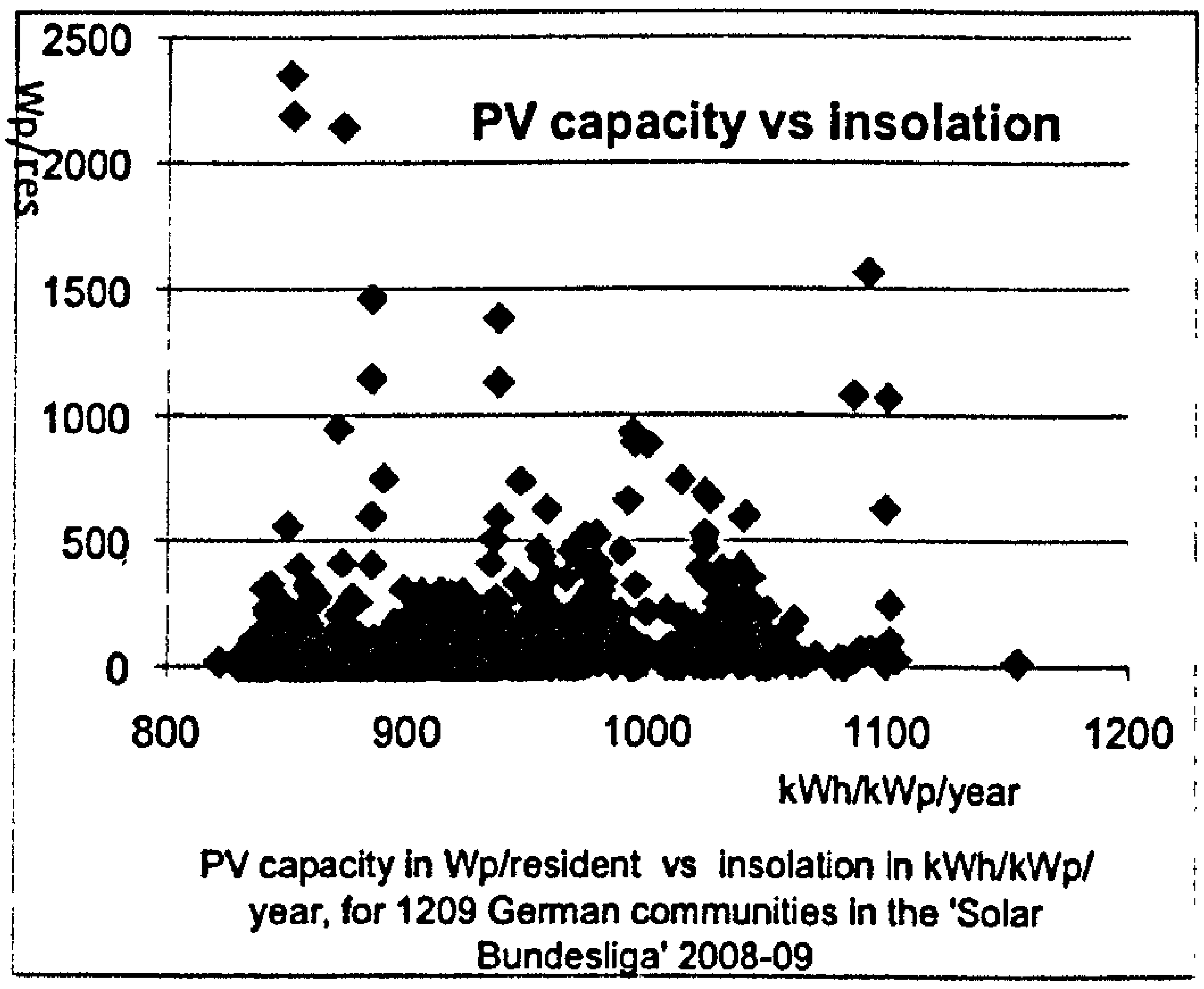


Figure 17 : PV capacity vs projected array output, 2008-09

The plot in Figure 17 above shows no evident correlation between projected PV system output for a given 'Solar League' location and the capacity installed there.

Capacity correlates quite strongly with projected output when aggregated in bands of 30 kWh/year/kWp of system capacity : $r_s = 0.721$, $p = 0.05$.

Total PV capacity in the Solar League towns in each 30 kWh system output band, i.e. without normalising for population, displays a strong *negative* correlation, r_s -0.788, $p = 0.02$.

There is no correlation (r_s -0.236) between the percentage increase from 2004 to 2008 in the number of towns in each Land participating in the Solar League, and the average PV system output. Nor with the increase in total PV capacity in participating towns, $r_s = 0.266$. Nor yet with the percentage increase in capacity in League towns in each Land: r_s -0.152.

Most Länder have a similarly narrow range of maximum and minimum projected outputs. In the southern Länder, Bayern and Baden-Württemberg, the maximum output is much higher - but even those Länder extend far enough north that the minimum output is in line with all others.

The conclusion from this rather broad brush analysis is that a good deal of PV capacity has been installed where output and hence feed-in tariff income are relatively low. The following describes the results of a somewhat more detailed analysis.

5.2.2 Analysis of sensitivity analysis model outputs

A fairly straightforward spreadsheet based model was used, as described in 4.2.3 earlier. Each run of the model with a given combination of <proportion of system cost borrowed>, <interest rate> and <loan term> generated a total expected return on investment (RoI), for each town in the Solar League dataset, arranged from lower to higher in line with projected PV system output. The total RoI was converted using a look-up table to the equivalent annual compounded rate of return. The towns were then grouped into RoI bands, as set out in Table 25 below, and the PV capacity installed in each of those groups summed, giving a profile to be presented in charts (see below).

Bands of expected return on investment	
0 to < 1.2%	little or no return
1.2 to < 2.4%	low return
2.4 to < 3.6%	similar to savings account
3.6 to < 4.8%	somewhat above savings account
4.8 to < 6.0%	clearly above savings account
6.0 to < 7.2%	high return
≥ 7.2%	"dream" return

Table 25 : expected return on investment in a PV system, compared with 'high street' savings account interest rates

An average RoI was calculated for the dataset for each combination of variables: proportion of system cost borrowed, interest rate and loan term. It was weighted by installed PV capacity, calculated simply by multiplying the RoI for each town by the capacity installed there, summing those figures across the 1209 (in 2008-09) or 1516 towns (2010-11), and dividing by total capacity installed in them. In all cases, the average RoI weighted by capacity is higher than the RoI in a PV system with projected output at the mean of all League towns (920.7 kWh in 2010-11) ; but only by about 0.2%. That therefore does not appear to be a strong indicator that the PV capacity is primarily going where the best expected returns are.

The principal output consists of Table 26 in 5.2.3 and Table 28 in 5.2.4 below, showing the weighted average expected RoI for each combination of variables, for the 2008-09 and 2010-11 analyses respectively. As noted above, the distribution of PV capacity by expected RoI band will also be presented, for a few selected combinations.

5.2.3 Weighted average RoI in 2008-09

% borrowed > / loan period, rate	50%	66.7%	75%
10 yrs @ 3.5%	2.81%	3.59%	4.27%
@ 4.0%	2.74%	3.46%	4.10%
@ 4.5%	2.66%	3.33%	3.92%
@ 5.0%	2.58%	3.19%	3.74%
12 yrs @ 3.5%	2.71%	3.41%	4.03%
@ 4.0%	2.62%	3.24%	3.81%
@ 4.5%	2.52%	3.07%	3.58%
@ 5.0%	2.43%	2.91%	3.35%
15 yrs @ 3.5%	2.54%	3.14%	3.64%
@ 4.0%	2.43%	2.91%	3.35%
@ 4.5%	2.31%	2.68%	3.04%
@ 5.0%	2.19%	2.45%	2.51%
20 yrs @ 3.5%	2.23%	2.61%	2.93%
@ 4.0%	2.10%	2.29%	2.48%
@ 4.5%	1.93%	1.96%	1.99%
@ 5.0%	1.72%	1.60%	1.44%

Table 26 : mean expected return on investment over 20 years in Solar League towns in 2008, weighted by installed PV capacity, for various combinations of proportion of system cost borrowed and loan terms

There is an evident gradient of expected return on investment from bottom left of Table 26 to top right. The anomalous figures in the '66.7%' and '75%' cells in the bottom row, and to a lesser extent in the row above that (both for 20 year loan term), arise because for those combinations of variables a significant number of Solar League towns have a *negative* expected RoI, as set out in Table 27 below, which naturally damps the overall weighted average.

Combination of variables	No. of towns	Total PV capacity
75% at 5% over 20 years	343	173 MWp
66.7% borrowed at 5.0% over 20 years	234	147 MWp
75% at 4.5% over 20 years	241	148 MWp
66.7% at 4.5% over 20 years	91	48 MWp

Table 27 : extent to which some combinations in sensitivity analysis of 2008-09 Solar League dataset produce negative expected return on investment (League total capacity = 748 MWp in 1209 towns)

Inspection of the horizontal and vertical sequences of figures in Table 26, disregarding the anomalous figures referred to above, reveals that the expected RoI is almost equally sensitive to the percentage of PV system cost financed by borrowing, ranging from 0.38-1.46% difference between combinations, and to the loan term, 0.86-1.34% difference. Sensitivity to interest rate is slightly less, the difference being from 0.23-1.13%.

Anecdotal evidence, for instance the worked example in Solarpraxis (2007), indicates that a loan term of 10-12 years is more common than one of 15-20 years. Typical interest rate in 2008 was 4.77% from the "Generate solar electricity" (author's translation) programme of the Kreditanstalt für Wiederaufbau, a government backed institution which finances energy efficiency and microgeneration (BSW, 2008b). Focusing accordingly on the figures for expected RoI in the upper half of Table 26 , they are in the range 2.43% to 4.27%. As set out in Table 25 on p.168, such returns are broadly comparable to those available from a 'high street' savings account, as referred to in Chapter 3.2.4.

Taking as representative the combination of 75% of system cost borrowed at 4.5% interest over 10 years, Figure 18 below illustrates that precisely half of the PV capacity installed in Solar League towns as of the 2008-09 'season' (374 MWp of 748 MWp total) was in locations where the expected RoI was 3.6 to <4.8%.

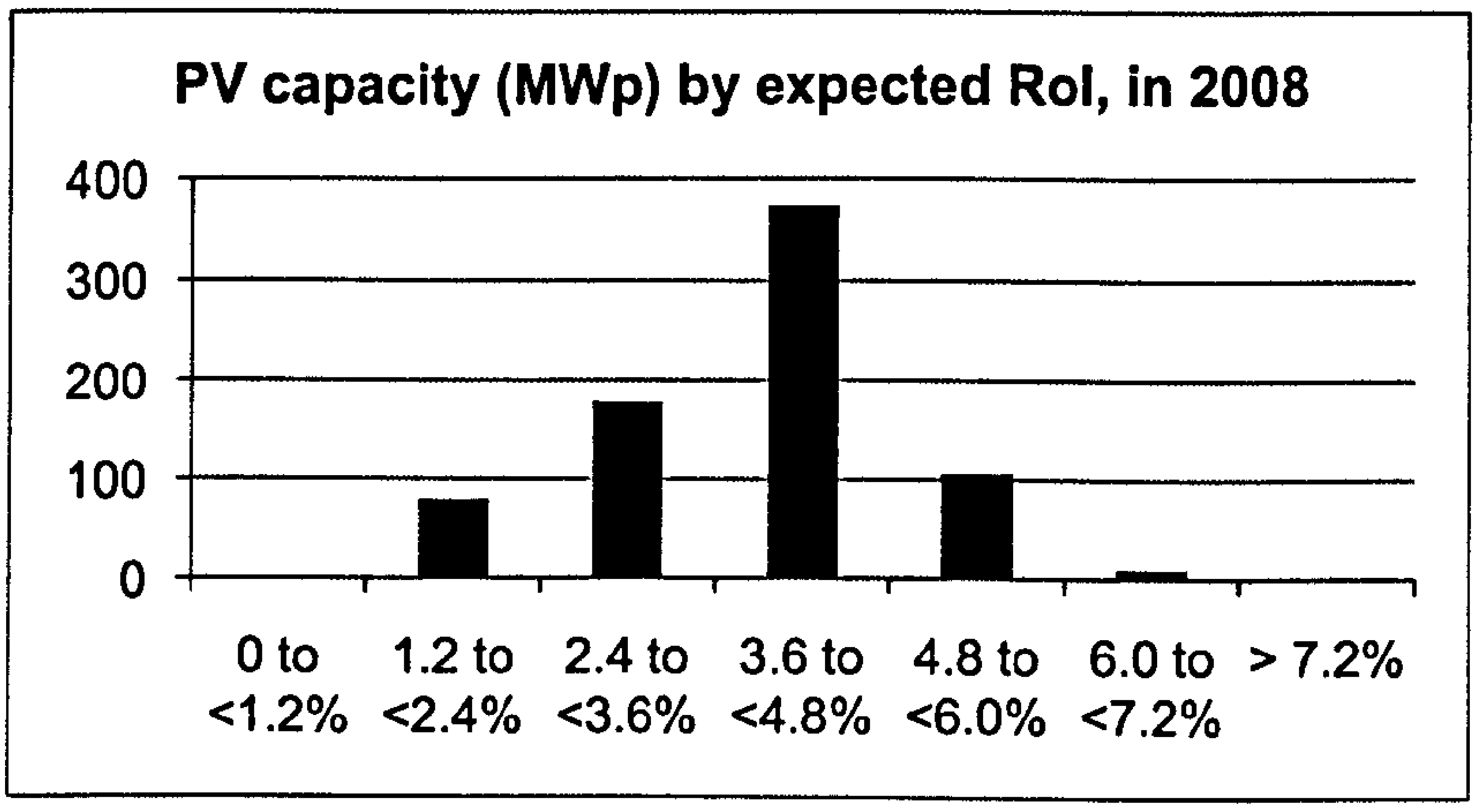


Figure 18 : distribution of PV capacity in Solar League towns, 2008-09 season, by band of expected return on investment; 75% of system cost borrowed at 4.5% over 10 yrs

That people in over 1200 towns, few of whom could expect a return clearly (meaning by ≥2%) exceeding that available on the high street, nonetheless went to the effort of having a total of 748 MWp of PV installed, and tied their money up for a lengthy period, strongly supports the hypothesis that profit was at least up to 2008-09 not the sole or principal driver of PV capacity growth in household rooftop systems.

5.2.4 Weighted average RoI in 2010-11

By the 2010-11 Solar League 'season' the picture had changed. As is clear from Table 28 overleaf, expected return on investment increased by 1.5-2.3% for the combinations involving shorter loan term. The League itself had grown, to 1516 towns with PV capacity installed, which totalled 2103 MWp, nearly three times the 2008-09 total. Does this mean that expectation of higher RoI, the result of the sharp fall in PV system prices, attracted many more householders to have PV installed? Or that added capacity in search of higher RoI was primarily in larger systems? Chapter 6.3 considers such market segmentation.

% borrowed > / loan period, rate	50%	66.7%	75%
10 yrs @ 3.5%	4.25%	5.37%	6.32%
@ 4.0%	4.17%	5.28%	6.20%
@ 4.5%	4.11%	5.19%	6.08%
@ 5.0%	4.06%	5.09%	5.95%
12 yrs @ 3.5%	4.15%	5.24%	6.15%
@ 4.0%	4.08%	5.13%	6.00%
@ 4.5%	4.01%	5.01%	5.85%
@ 5.0%	3.94%	4.89%	5.70%
15 yrs @ 3.5%	4.03%	5.04%	5.89%
@ 4.0%	3.94%	4.89%	5.70%
@ 4.5%	3.85%	4.74%	5.50%
@ 5.0%	3.75%	4.58%	5.29%
20 yrs @ 3.5%	3.82%	4.69%	5.43%
@ 4.0%	3.70%	4.47%	5.15%
@ 4.5%	3.56%	4.25%	4.85%
@ 5.0%	3.43%	4.02%	4.56%

Table 28 : mean expected return on investment over 20 years in Solar League towns in 2010, weighted by installed PV capacity, for various combinations of proportion of system cost borrowed and loan terms

There is once again an evident gradient of expected return on investment from bottom left of Table 28 to top right. The arithmetical mean of weighted average RoI for each of the input variables, across the range of the other two variables, is as follows.

* % of system cost borrowed: 4.39% for 50%, 5.39% (66.7%), 6.34% (75%)

* loan period: 4.29% for 10 yrs, 4.16% (12 yrs), 4.01% (15 yrs), 3.71% (20 yrs)

* interest rate: 4.19% (for 3.5%), 4.09% (4.0%), 3.99% (4.5%), 3.90 (5.0%).

The expected RoI is sensitive primarily to the percentage of PV system cost financed by borrowing, being from 1.13% to 2.07% higher with 75% borrowed than for 50% borrowed. Figure 19 overleaf shows the effect of percentage borrowed on the amount of capacity in the various bands of expected RoI. There is somewhat less sensitivity to the loan period: expected RoI is at most 1.29%

higher in the case of 75% of cost borrowed at 5% interest, over 10 and 20 years respectively; and in most cases is less than 1% higher. Least sensitivity is displayed to the interest rate, which in all but three cases makes a difference of less than 0.5% to expected RoI, and a maximum of 0.87%.

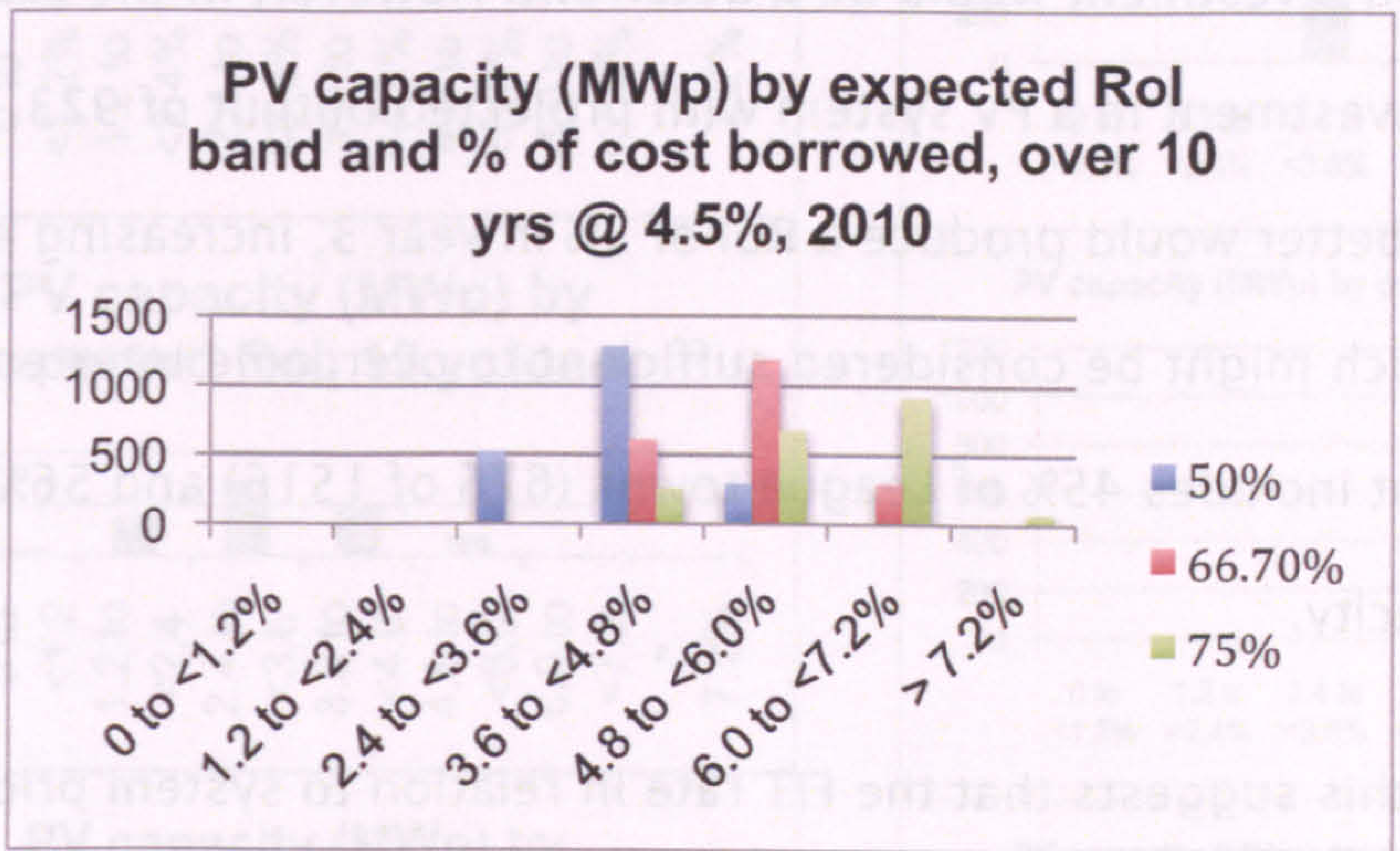


Figure 19 : effect of increasing percentage of PV system cost borrowed on expected RoI ; Solar League towns, 2010-11

That is not too surprising, since a higher proportion of loan financing will correspondingly reduce the level of own capital employed, relative to which the RoI is calculated (profit/OCE x 100). To illustrate that effect further, an additional four runs were made with combinations involving 90% of PV system cost borrowed - over 12 yrs at the four interest rates. Those runs generated weighted average RoI from 9.9%-10.1%. It is evident that financing almost the whole cost with a loan results in very high return. But in that case the investment is only about €1400 (10% of 4 kWp system cost in 2010), so even a 10% return means just €140. Would anyone really go to the trouble and time of arranging a loan, PV system purchase and installation, for such a small interest income, rather than seek a similar return from a small investment in a professionally run Solar Fund?

For the combination '75% borrowed @ 4.5% over 10 years' at 2010 system price and FiT rate, the weighted average RoI is 6.08%. There is a positive balance of FiT income over loan repayment + interest from year 1, for projected system output of 882 kWh and above, which covers 70% of League participants (1059 towns) and 75% (1578 MWp) of total capacity. A legitimate question, since theory of intertemporal choice tells us that people tend to be reluctant to invest up front for a future gain (3.7.5.5 earlier), is whether the prospect of a year or more of low profit and return on investment would be a deterrent. However, in the case of this combination, an investment in a PV system with projected output of 923 kWh/kWp/year or better would produce a RoI of 3% in year 3, increasing each year following, which might be considered sufficient to overcome intertemporal concerns - and that includes 45% of League towns (676 of 1516) and 56% (1187 MWp) of total capacity.

On the one hand, this suggests that the FiT rate in relation to system price was too high in 2010, making it attractive as a pure investment. On the other, the indicated returns are in the 5-8% range that the architects of the EEG and FiT envisaged. Moreover, a return of some 3% above that from a savings account (weighted average RoI as above, 6.08% minus typical savings interest rate 3%), on own capital amounting to 25% of system cost, i.e. €3500, means extra earnings of €105 per annum or €9 a month. The same question as in the last but one paragraph above applies: if level of return is the primary consideration, why go through the process of having a PV system installed instead of simply investing the same sum of money in a Solar Fund offering a return in the region of 6%?

Effect of loan term on distribution of PV capacity by expected return on investment, 2010-11 and 2008-09

The charts overleaf (Figures 20, 21) show total PV capacity installed in Solar League towns, in 1.2% wide bands of expected RoI, for the case of 75% of system cost borrowed at 4% interest over various loan terms. This illustrates how the level of expected RoI increases as the loan term shortens; and how expected RoI became substantially higher in 2010-11 than it was in 2008-09.

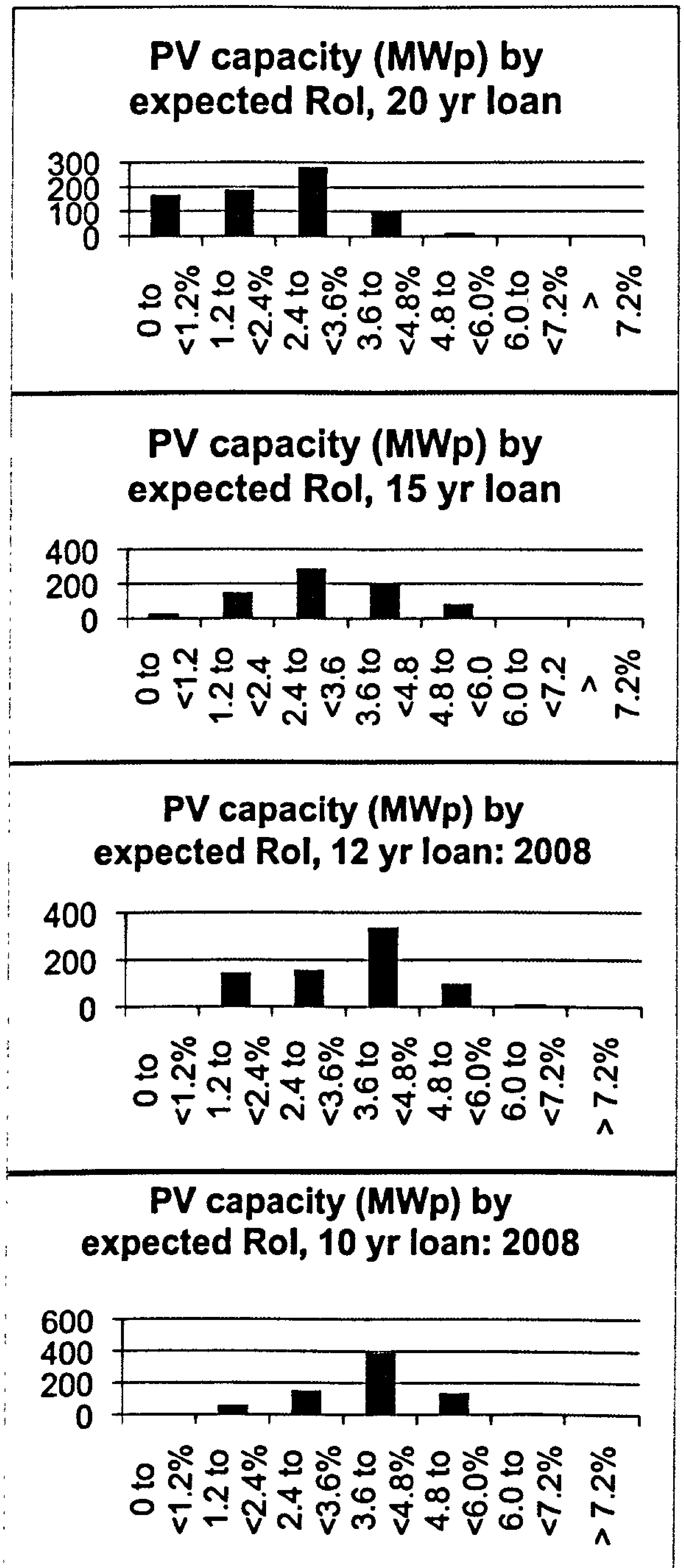


Figure 20 (four charts): capacity distribution by expected RoI and loan term, 2008-09

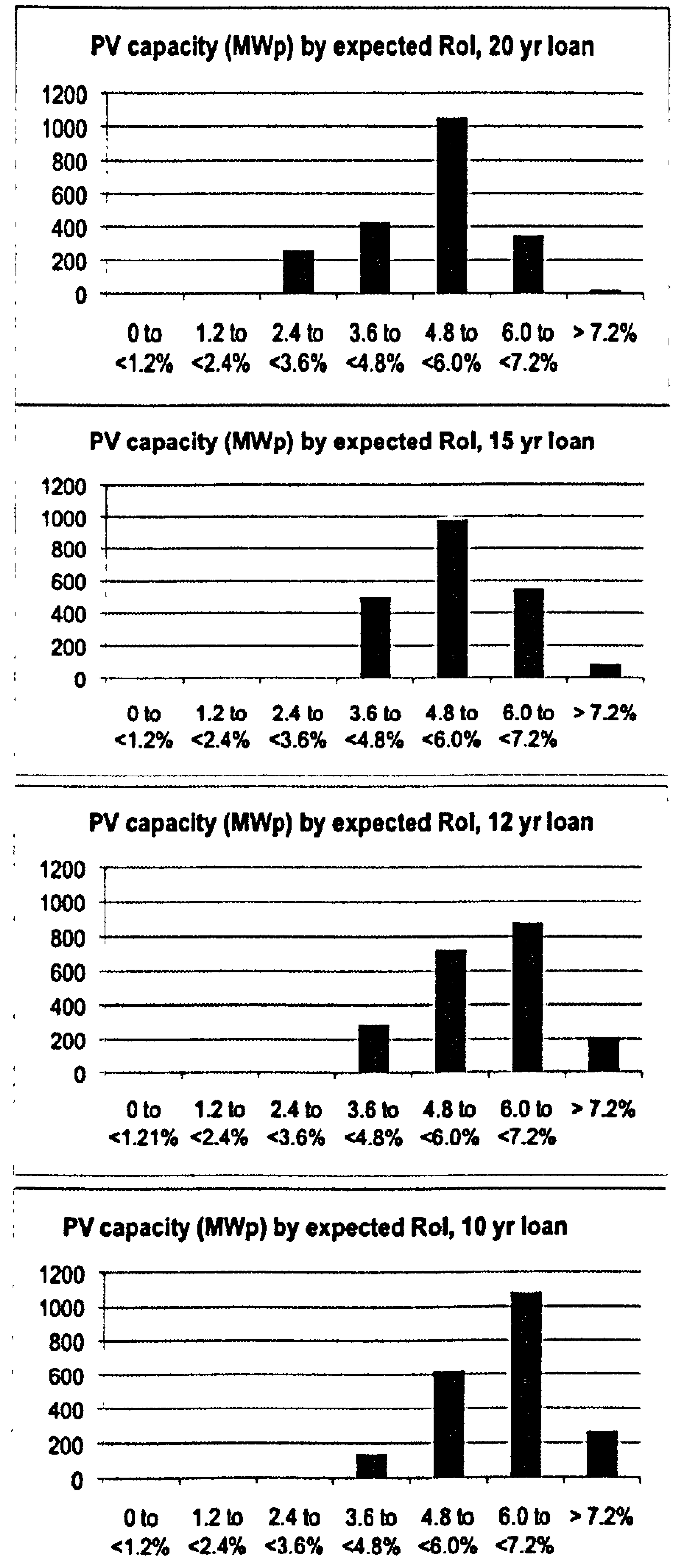


Figure 21 (four charts): capacity distribution by expected RoI and loan term, 2010-11

Chapter 6 : Outlook to 2020

"If there is one lesson to be learned from history it is that those who believe that they have the final truth and that they know what is good and right for the rest of us are almost certain to be mistaken."

David de Vaus, 2002, p.210.

6.1 Introduction

The prospects for sustained growth of PV in Germany in the period to 2020 depend on the extent to which the principal drivers of the growth so far will continue to operate. The most recent 'forsa' survey (see 6.2.3 on p.183 below) shows that public support for renewables remains strong. There is nothing to suggest that environment consciousness in Germany has lessened; if anything, increased support for the Greens indicates the opposite. Accordingly, this chapter will focus primarily on whether feed-in tariff incentives are likely to remain in place, in terms of politics, criticisms of PV support costs, and the approach of 'grid parity' (see 6.7 below); and on the outlook for regional and global PV markets, and for developments in technology and production scale, and the potential impact of those factors on the cost of PV systems. As in the preceding chapters it will, within the context of overall PV demand, consider more closely the domestic market segment.

The interplay of FiT rate, PV system cost and output in kWh affects projected return on investment, as described in Chapter 5 above. Within the spectrum of levels of return required to motivate uptake of PV, in the "desire push-incentive pull space" postulated in 1.5 (page 10), the findings presented in Chapter 5 indicate that the domestic segment of the German PV market does not depend on a high FiT rate.

6.2 Politics

6.2.1 Political position since 2005

The right of centre parties in the German political spectrum are the Christian Democratic Union (CDU) led by Angela Merkel, its Bavarian sister party the Christian Social Union (CSU), and the Free Democratic Party (FDP). These three parties are widely perceived as more "business-friendly" than the left of centre Social Democratic Party (SPD) and Greens, and the neo-socialist Die Linke. The FDP present themselves as "Liberals", but in economic terms that means proponents of free market capitalism, and pro-business. One view (Michel, 2009) is that they also oppose subsidies for special interest groups, including in that category the renewable energy sector and hence the feed-in tariff. The FDP, however, at its party conference in May 2009 abandoned its opposition to the Renewable Energy Sources Law which enshrines the feed-in tariff (Morris, 2009).

CDU/CSU (together also known as 'die Union') and FDP adopted in the 2005 federal election campaign policies of 'market reform' and 'labour flexibility'. Enough voters evidently perceived those policies as threatening the German "social market" model, that the election outcome denied Union+FDP an overall majority, and led to a Grand Coalition between Union and the SPD, with Angela Merkel as Chancellor because leader of the largest parliamentary party.

The SPD were able in the Coalition Agreement to preserve the Renewable Energy Sources Law (in German, EEG), with its crucial provisions for feed-in tariffs to promote growth of renewable energy capacity and for guaranteed priority grid access for the electricity it generates. The SPD also retained the Environment Ministry, which moreover kept responsibility for renewable energy policy, fending off Union attempts to transfer that to the Economics Ministry under Clement (also SPD) who favoured a "market based" approach. That outcome thus continued the renewables promotion policy of the previous 'Red-Green' government of SPD and the Greens, which created the EEG and feed-in tariffs, as described in 3.3.3 earlier.

So far (was) so good for PV in Germany. The rapid growth of capacity continued, as shown in Table 29 below. Total new capacity installed in the four years between the 2005 and 2009 federal elections, approximating that as the sum of installations in 2006, 2007, 2008 and 2009, was 7820 MWp. That means that 80% of the total cumulative PV capacity installations from 2000-2009 took place in that four year period. One could call it a "golden age" for PV in Germany ; but perhaps also a wake-up call to the established electricity industry which led to the critical attacks on PV described in 6.3 below.

Year	Capacity added (MWp)	annual growth	Total installed capacity (MWp)	Electricity generated (GWh)
2000	44		76	64
2001	110	145%	186	76
2002	110	59%	296	162
2003	143	48%	439	313
2004	635	145%	1074	556
2005	906	84%	1980	1282
2006	832	42%	2812	2220
2007	1165	41%	3977	3075
2008	2017	51%	5994	4420
2009	3806	63%	9800	6200

Table 29 : Development of PV capacity and electricity output in Germany 2000-2009 (source: "Renewable Energy Sources in Figures" 2010 English edition, German federal environment ministry, June 2010)

6.2.2 Energy policy of the Grand Coalition

In recent years reports and policy papers from the German government, and in particular from the Environment ministry, have been positive about renewable energy. The "Lead Scenario 2006" for development of renewables (Nitsch, 2007) foresaw their share of electricity consumption rising from 12.5% in 2005 to 79.4% in 2050. The scenario's projections for primary energy sources are set out in

Figure 22 below: note the rapid decline of nuclear power, and that all fossil energy sources also reduce, especially coal.

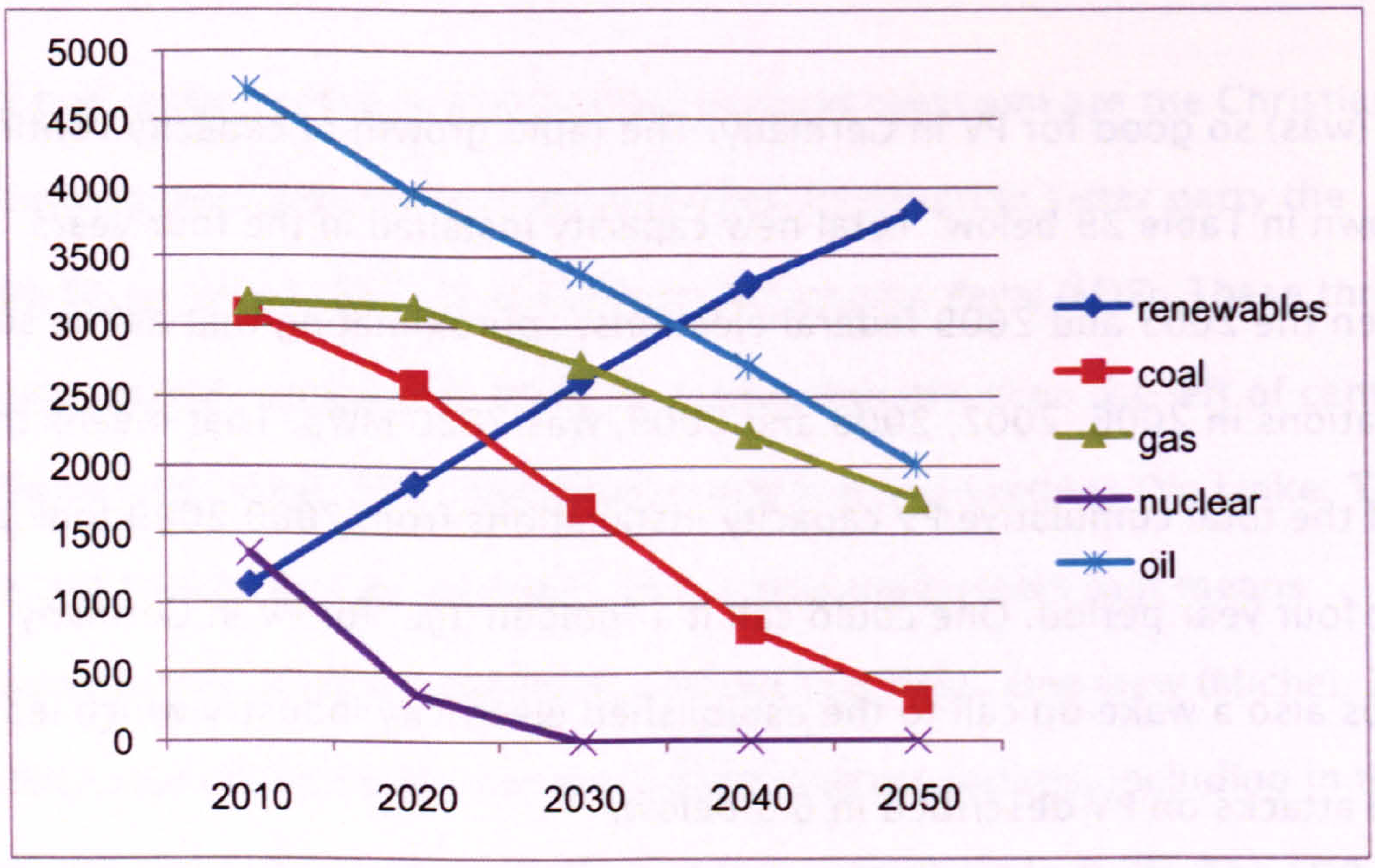


Figure 22 : primary energy output in PJ/yr, projected in Lead Scenario 2006 (data from Nitsch, 2007)

(The scenario is concerned with how to achieve deep cuts in CO_2 emissions, therefore includes oil as a primary energy source; it has as previously noted a very minor role in electricity generation. Gas is of course also used for heating and cooking.)

The Environment ministry paper of April 2007 on CO_2 emission reductions up to 2020 (BMU, 2007a) emphasised increasing renewables' share of electricity output to 27% by that year, along with energy efficiency and renovation of the power station fleet including a doubling of combined heat and power.

The same Ministry issued (BMU, 2007b) an English language summary of the energy and climate programme agreed by the Grand Coalition government at Meseberg in August 2007. It includes the same measures as just described, with power station modernisation to include carbon capture and storage (CCS) and "clean power station technologies". The latter is not further explained, so it is not clear whether it goes beyond combined heat and power (CHP) and CCS, both already separately listed among CO_2 emission reduction measures.

On coal, there is an explicit statement: ""What is clear is that the construction of new [power] plants must be compatible with the German government's climate protection target of reducing greenhouse gas emissions by 40% below 1990 levels by 2020. Against this background, beyond the coal-fired plants already under construction there is no leeway for coal-fired plants that are not CHP plants or fitted with CCS technology." (ibid, p.10). As of March 2009, 8 new coal-fired power stations were under construction in Germany, with total capacity of 9.620 GW ; and a further 21 are planned, total capacity 22.023 GW (Hannen, 2009b). Of the overall projected capacity of 31.643 GW, 15.680 GW is at plants clearly of the four major electricity companies or subsidiaries; others may be, but are not immediately identifiable as such. It will be interesting to observe which of the planned power stations are in fact built, and whether they indeed are CHP or CCS equipped.

Interestingly, there is no direct reference in the Meseberg programme to nuclear energy. Perhaps the CDU/CSU side of the coalition intended it to fit under "clean power station technologies". Its views on nuclear energy were set out clearly in BMWi (2008), in the name of the then minister Michael Glos (CSU): "In an energy policy based on economic viability, security of supply and climate protection, Germany should also in the future not dispense with the contribution of nuclear energy to electricity generation." (author's translation). The paper puts forward a potential electricity supply mix of one third each renewables, nuclear and CCS equipped coal and gas. It clearly implies that nuclear would act as a "bridge technology" at least until 2030.

6.2.3 Election 2009 : swing to the Right

The Union and FDP got another chance in the federal election of September 2009. This time, against a background of economic downturn and the global financial system crisis, the three parties collectively won an overall majority of seats and formed a centre-right government, with Dr Merkel continuing as Chancellor.

In the election campaign, the electricity majors and their allies renewed calls for a sharp reduction in the feed-in tariff for PV. The FDP proposed a 30% cut. Those calls naturally intensified after the Union+FDP victory; as did the same actors' campaign for abandonment of the legally mandated phase-out of nuclear power, at least to the extent of extending the operating lifetime of some power plants. Since the plants are already amortised, additional operating time would bring significant extra profit to the major electricity companies.

An earlier indication of a cautious approach by the new government came in remarks at the opening of the 24th PV Solar Energy Conference in Hamburg on 21 September 2009 (author present), a few days before the election. Joachim Nick-Leptin of the federal Environment Ministry doubted that a Union-FDP coalition government would extend nuclear plant operating life *and* drastically cut the PV feed-in tariff *and* damage Germany's solar industry: those would all be unpopular with voters. He did not expect significant change before the next scheduled review of the EEG in 2011. As it turned out, he was unduly optimistic.

The German press reported (for example Der Spiegel, 2009b) that in their formal Coalition Agreement the government parties declared their support for climate protection and the build-up of renewable energy; the latter, however, primarily through development of offshore wind farms and of biomass energy. At the same time the parties announced that they wished to review the solar PV promotion scheme. The new federal Environment Minister, Norbert Röttgen (CDU) stated that developments in the PV market had led to "clearly excessive support", and that a support mechanism was required which would react flexibly to market developments; he would seek an appropriate solution together with the solar industry and consumer representatives.

The latest opinion poll about renewable energy by the forsa Institute confirms the enduring strong support for renewables among voters (forsa, 2009a). 95% regard the build-up and increased use of renewables as "important" to "extremely important". Overall 76% want incentives, including feed-in tariffs, to be kept at their present level; even 71% of FDP, and 73% of CDU/CSU voters hold that view. It seemed unlikely that the new government would rush into an action, namely sharp cuts in the PV feed-in tariff, which on the basis of this poll would be unpopular even with nearly three-quarters of its own voters. In Germany's proportional representation electoral system, parties have to be especially sensitive to public opinion; the more so as there are Land elections in between federal ones, which determine who controls the upper house (Bundesrat).

The majority of solar companies accepted that there should be a moderate additional reduction in the feed-in tariff for PV, of up to 5% over the next two years, on top of the annual taper prescribed in the EEG. A study for the industry association BSW, by the Fraunhofer Institute for Solar Energy in Freiburg (Stryi-Hipp, 2010), concluded that a one-off reduction during 2010 of 6% would be justified in relation to PV module price movements. It warned that while a larger reduction would not prevent further market growth, it would lead to Asian (primarily Chinese) PV producers gaining market share by selling below real production cost, and to a reduction in PV manufacturing in Germany.

6.2.4 Outcome: a 16% feed-in tariff cut

A blow by blow account of the debate in the first half of 2010 about the extent of the supplementary PV FiT cut would occupy disproportionate space; following is a brief summary of the key developments.

On 20 January 2010, Environment minister Röttgen announced proposals (reported in, for example, Fuhs & Enkhardt, 2010).

- Supplementary cut in rooftop PV FiT of 15% from 1 April
- Annual PV capacity growth target of 3 GWp. If growth exceeds 3.5 GWp, annual FiT degression to increase by 2.5% ; if over 4.5 GWp then a further 2.5% increase in degression (i.e. +5% overall). Conversely if growth under 2.5 GWp, degression reduces by 2.5%, by 5% total if growth below 2 GWp.
- FiT for ground-based arrays cut by 15%, but from 1 July ; FiT for PV on greenfield sites cut by 25%.
- FiT rate for in-house use of PV electricity to increase slightly, creating a premium of 8€¢ per kWh relative to payment for feed-in to the grid.

Criticism swiftly followed, with warnings of the threat to Germany's PV industry and employment. The industry association BSW said that the proposed measures would make Chancellor Merkel's climate policy rubbish (BSW, 2010a), and cited an analysis by the Landesbank Baden-Württemberg that a PV FiT cut of 10% or more would hand market share to Chinese producers and seriously damage the European industry (BSW, 2010b). The solar promotion association SFV pointed out that companies had made investments several years earlier in the expectation that the then prevailing FiT degression of 5% would continue, and would now struggle to survive (SFV, 2010b).

The governments of four eastern Länder - Brandenburg, Sachsen, Sachsen-Anhalt and Thüringen - and of Bayern criticised the proposed FiT cut as threatening their substantial PV industries. Mecklenburg-Vorpommern (Dr Merkel's home state) called for prior agreement with the Länder on such measures. Rheinland-Pfalz, Bremen, Hamburg and Saarland also opposed the proposed cut. (Example references collected in 'Länder vs FiT cuts, 2010'.) Comments from the main opposition party SPD were by comparison muted, accepting that a "substantial" reduction in the PV FiT was feasible, and calling only for the proposed cut to be put back to 1 July to avoid harming projects already planned (SPD, 2010).

Naturally the Greens were vociferous in opposing the proposed cuts. Their energy spokesman Hans-Josef Fell set out a detailed position in April 2010 (Fell, 2010b), including such cogent points as that the sharp fall in PV module prices reflected the collapse of the Spanish market rather than a corresponding fall in production costs, and that the Greens had from the start sought a PV support mechanism which delivered reasonable, but not excessive, returns on investment. The Greens proposed adjusting the PV FiT to a level which would both avoid excessive reward and still enable German producers to remain in the market: a reduction of 6% for systems up to 10 kWp, and of 10% for larger systems. In the end, opposition efforts to challenge and block the proposed measures were overridden. The government deemed that the measures did not require approval in the Bundesrat (upper house). The sole concession was that the PV FiT cut of 16% for arrays on rooftops took effect in two stages, 13% from 1 July and a further 3% from 1 October. FiT support was removed altogether for PV on greenfield sites.

6.2.5 Will PV withstand the support cuts?

The German PV industry will have to live with a reduction in the feed-in tariff much greater than that already scheduled under the terms of the EEG, albeit not on the scale advocated by the FDP and solar critics such as RWI (see 6.3.3 below). If, as noted above, the cut simply brings FiT rates back to a level sufficient to incentivise investment in PV, without providing a rate of return greater than that involves, manufacturers may through continuing cost reduction measures be able to repair some of the damage done to their margins by the module price fall of 2009. That fall would in effect have 'anticipated' future cost reductions, causing a period of reduced margins that, however, the more efficient producers could weather. The updated "growth corridor" provisions in the FiT mechanism at least give the industry some indication of what future rates will be - provided that the government does not embark on further FiT cuts in the biennial review of the support mechanisms under the Renewable Energy Sources Law, to take place in 2011. Parliament agreed in late February a further in-year FiT rate cut as from 1 July 2011, of up to 15% depending on growth in the March-May period (Enkhardt, 2011a). The challenge for the industry will be to achieve corresponding cost reductions. Where those might come from, is discussed in section 6.5 below.

6.2.6 Nuclear power

The language of defenders of the existing supply paradigm has shown some interesting shifts. Advocates of nuclear power in Germany no longer assert that it is indispensable *for the long term* to maintaining electricity supply while reducing CO_2 emissions. Instead, they refer to it as a "transitional technology" to provide lower carbon generation until renewables take over, and have argued for extension of permitted nuclear plant operating lifetimes. A Stuttgart University study (Hundt et al, 2009), commissioned by E.On, concluded that extending the operating lifetimes of nuclear power stations would be compatible with a growing share of renewable energy in electricity generation, on the grounds that nuclear plant output could be adjusted flexibly enough to operate in load-following, not solely baseload, mode. Analysis by Keles et al (2011) found that renewables would supply the majority of electricity by 2030 under all scenarios, including that of a revision of the nuclear phase-out. The new Environment Minister has stated clearly that there is no question of revoking Germany's eventual withdrawal from nuclear power, as required by law (for example Röttgen 2009), since there is no majority among voters for that. The CSU environment spokesman issued an assurance that priority grid access for renewably generated electricity would be maintained, even if nuclear plants operated for longer (Nüßlein 2009).

An early presentation of the argument that nuclear power be needed as a "transitional technology" was by the then Environment minister of Baden-Württemberg, Tanja Gönner, quoted in Breining (2006). She somewhat called into question the credibility of her position, however, by suggesting that the recent problem at the Forsmark reactor in Sweden - failure of power which damaged safety systems and could have led to disaster (Der Spiegel, 2006) - demonstrated high safety standards; and by referring to nuclear power plant operation as "CO_2 free", which may be narrowly correct at the point of generation, but ignores significant emissions in the nuclear fuel cycle (Sovacool, 2008).

In November 2010 the Bundesrat (upper house) approved the extension of nuclear plant operating lifetimes, together with a new tax on nuclear fuel rods to come into effect from January 2011. The tax is projected to raise €2.3bn; however, the electricity companies are allowed to offset it against their other tax payments (making it a rather novel tax-deductible tax), reducing the revenue by €500-600m (Fell, 2010c). The Green party and five Länder planned to challenge the decision in the constitutional court. Meanwhile major protests have continued, like the demonstration by 100,000 in Berlin in September 2010. As one UK commentator put it, "No-one in the government dares to even consider new replacement plants, much less a nuclear expansion." (Elliott, 2010a).

The German government has referred to the nuclear plant operation extension as being on average for 12 years (for example, BMWi & BMU, 2010, p.14). However, the energy spokesman for the Greens, Hans-Josef Fell, believes that the enabling law will define the extension in terms of TWh of ouput, rather than of years of operating time (Fell, 2010c). That would imply either running nuclear power stations continuously to reach the permitted extra output in as short a time as possible; or that they could in practice operate beyond the 'headline' number of years, should their output be reduced by operating problems. The four electricity majors at one point made a bizarre threat to shut down nuclear power stations if the government imposed the fuel rod tax, as reported by Hawley (2010). He also quotes Die Welt as pointing out the contradiction between claims that without nuclear power Germany would face electricity shortages, and the shutdown threat, which implied that nuclear power was after all dispensable.

6.2.7 The role of coal

The SPD has for political reasons consistently supported the coal industry especially in the Ruhr region, which receives large subsidies not finally to be phased out until 2018 (Wedekind, 2007). That led to contradiction and tension between support for renewable energy and for continued use of coal. For example, Fell (2008) bitterly criticised the then Environment minister Gabriel (SPD) over his proposal to use receipts from CO_2 emission permits to subsidise coal fired power stations, describing him as following a long line of SPD ministers who looked after the interests of the major electricity companies. Although Gabriel was also a staunch defender of renewable energy and the feed-in tariff, his ambivalent position may have played into the hands of the major electricity companies by encouraging continued operation of coal fired plant, and thereby of the large scale centralised generation paradigm.

The recent "dash for coal" is analysed in detail in Pahle (2010), who finds the main reasons to be: need to replace phased out nuclear capacity, new energy industry investment cycle, coal's long term prospects better than gas, bias in favour of the existing system, political support for coal, and ineffectiveness of public protests. The claimed need to replace nuclear capacity is now reduced, by the government's decision to extend plant operating lifetimes. If planned coal projects nonetheless go ahead, that will increase the conflict between centralised large scale generation and renewable energy. It will also mean conflict between energy and climate policy, since it will undermine the claim that nuclear is needed as a lower carbon "bridge" to the renewables age, which makes rather more sense if nuclear replaces coal. Relying on an energy supply mix including a still major proportion of coal fired plants implies an assumption that carbon capture and storage will work, as and by when required: see discussion of that topic in 6.3.8 below. It also implies undervaluing shale gas as a new source.

6.2.8 Policy outlook

The new German government made positive noises about renewable energy, and solar in particular, as reported in Enkhardt & Vorsatz (2010). In its coalition agreement it supported the further build-up of renewable energy and maintenance of the Renewable Energy Sources Law, and described solar as "an important future technology for Germany". Coalition partner the CSU agreed its own position on energy policy in April 2010, stating that renewable energy is the key to future energy supply, setting a goal of 40% renewable electricity supply in Bayern by 2030, and calling for an R&D push on smart grids (CSU, 2010). The coalition agreement pledged "dialogue with the solar industry about adjustments to avoid *short term* excessive PV support" (emphasis added). It argued that it was necessary to realign the PV feed-in tariff to lower system prices. Those fell as a result of oversupply owing to the collapse of the Spanish market; competition from Chinese producers seeking to gain market share made it difficult for selling prices to recover.

So in pushing through the 16% in-year supplementary PV FiT cut, was the government acting in good faith to prevent excessive returns for investors in PV who could undertake arbitrage between PV FiT rate and system prices? The government argued that the fall in module costs made such a "realignment" necessary. On one view, that was an example of the experience curve effect being so successful in driving manufacturers to reduce costs at least in line with the FiT degression, that the linkage flipped to falling *cost* of PV driving down the level of *support*, instead of the converse. Or did it take advantage of an unusual module price drop, which resulted from a temporary glut of modules no longer going to the Spanish market, and seize an opportunity to cut the PV FiT to apply a brake on PV capacity growth, on behalf of the established electricity supply industry?

The opinion of the German Green party is, not surprisingly, the latter. In a formal statement in May 2010: "The parliamentary Green party accuses the government that, with this first amendment of law in the energy field, it has failed to put into practice what it announced in the coalition agreement. We see much more an attempt to weaken the renewable energy sector, in order to achieve long term protection of the position of nuclear and coal power plants." (Greens, 2010). On the government's insistence on extending nuclear plant operating life, in the face of large demonstrations in autumn 2010 against nuclear power, the Greens' energy spokesman said: "One can no longer, under the CDU/CSU-FDP government, speak of representation of the citizens by the governing parties." (Fell, 2010d, author's translation). The government suspended the operating life extension in March 2011, for safety checks prompted by the Fukushima crisis.

Environment minister Röttgen has repeated the claim that nuclear power is needed as a bridge into the renewable energy age, in which Germany would achieve 80% renewable electricity supply by 2050 (Röttgen, 2010). He adds that the renewables age will require an infrastructure of smart grids and energy storage, which will take time and on which there has been virtually no progress in the last ten years. Leaving aside the point that for four of those years CDU/CSU were in the Grand Coalition government, Röttgen's formulation leaves the timescale for the infrastructure development unclear. The government's new Energy Concept (see below) refers variously to "a concept for a target grid for 2050", to ten year plans for grid upgrading, to development of smart grids but with no timescale suggested, and to boosting energy storage "in the long term" (BMWi & BMU, 2010).

Recent opinion polls in Germany, reported in for example Graham & Busemann (2010), have shown a surge in support for the Greens: 22% nationally, double their historical level and only just behind the SPD; and 25% in Baden-Württemberg which could be enough to give them the prime ministership of that Land in regional elections on 27 March 2011. It may be that the threat of such a serious political loss, coming on top of the loss of Nordrhein-Westfalen in 2010, will lead the federal government to think hard before pursuing any further measures damaging to renewable energy and the solar industry. Polls put support for the FDP perilously on the 5% threshold for representation in parliament. The prospect of winning no seats might likewise give the FDP food for thought.

The annual synod of the Evangelical-Lutheran church (German acronym EKD) called on the government to hold to the nuclear phase-out schedule, to abandon plans to extend nuclear plant operating lifetimes, and to convert energy supply to renewables as quickly as possible (EKD, 2010a). With around 25 million members or 30% of the population (EKD, 2010b), only slightly fewer than the Catholic Church, the EKD clearly has considerable influence.

On the other hand, Chancellor Merkel's insistence on pushing through extension of nuclear plant operating lifetimes, despite widespread opposition and survey results (forsa, 2009b) showing that 47% even of CDU/CSU voters want the timetable for the nuclear phase-out maintained or accelerated, indicates a degree of determination - or stubbornness. It could well qualify for the fictional Sir Humphrey's epithet of "courageous": " 'Controversial' only means 'this will lose you votes'. 'Courageous' means 'this will lose you the election'. " (Lynn & Jay, 1984).

The claimed justification for capping PV growth is that the increase in FiT payment costs risks damaging public acceptance of renewable energy. That is a line of argument often deployed by PV critics, who seek to blame on FiT costs the increases in electricity prices which 400 suppliers announced would come into effect from the beginning of 2011. The head of the federal grid agency has, however, stated that renewable energy is not responsible for price rises, but on the contrary has a price damping effect by displacing expensive conventional power stations (Enkhardt, 2010a). Zoellner et al (2008) found, from a survey in Germany, "a low degree of faith in facts and figures" in the media, perceived as inconsistent and contradictory.

There have been calls from within the CDU for further action to restrict the growth of PV. The energy spokesman of the parliamentary party Thomas Bareiß has, as reported by Fichtner (2010), suggested a further in-year FiT cut during 2011, and consideration of a limit of 3 GWp on annual PV capacity growth. The expert advisory committee on environmental issues, German acronym SRU (2011), has called for a 1 GWp cap on annual PV growth in order substantially to reduce support costs. At the same time, however, it advises retaining unchanged the guaranteed grid access and fixed feed-in tariff rate, warns that a Europe-wide feed-in tariff (see 6.2.10 below) would adversely affect the further build-up of renewable energy, and asserts that 100% renewable electricity supply is achievable without any nuclear plant operating life extension or new coal-fired capacity.

The latest development is that the solar industry association BSW proposed a further in-year FiT rate reduction of up to 15% as from 1 July 2011, apparently with the hope of averting imposition of a cap on annual PV capacity growth. As reported in Enkhardt (2011b), the CDU/CSU and FDP signalled agreement and environment minister Röttgen stressed that there is no question of reform of the Renewable Energy Sources Law (EEG) or of a "new element", which probably means no cap or removal of priority grid access. On the other hand, CDU spokesman Bareiß maintains that in the forthcoming biennial review of the EEG all options are still on the table. The Greens proposed instead frequent small reductions in the FiT rate, rather than one-off large cuts, in the interests of market stability. As announced by the BSW (2011), the German parliament in late February agreed the supplementary in-year FiT reduction. A cut of 3% is to take effect if projected annual PV capacity growth in 2011 exceeds 3.5 GWp, calculated as 4x actual new installations in March–May; with an additional 3% cut for each GWp of new capacity above 3.5 GWp, thus growth of 4.5 GWp would mean a 6% FiT reduction from 1 July 2011. The aim is to keep annual growth within the range 3–5 GWp, so that the extra cost to electricity consumers of PV support does not exceed €¢2 per kWh.

The solar promotion association SFV rejects both a cap on new capacity and FiT cuts to limit growth (von Fabeck, 2011). It argues instead that PV should be left to grow as rapidly as the German economy allows, anticipating that the growth will naturally slow as suitable space for PV systems becomes unavailable, displaying a logistic curve reaching 30% of the electricity supply as in Figure 23 below. The similarity to the S-curve of Rogers' (2003) innovation diffusion theory is apparent.

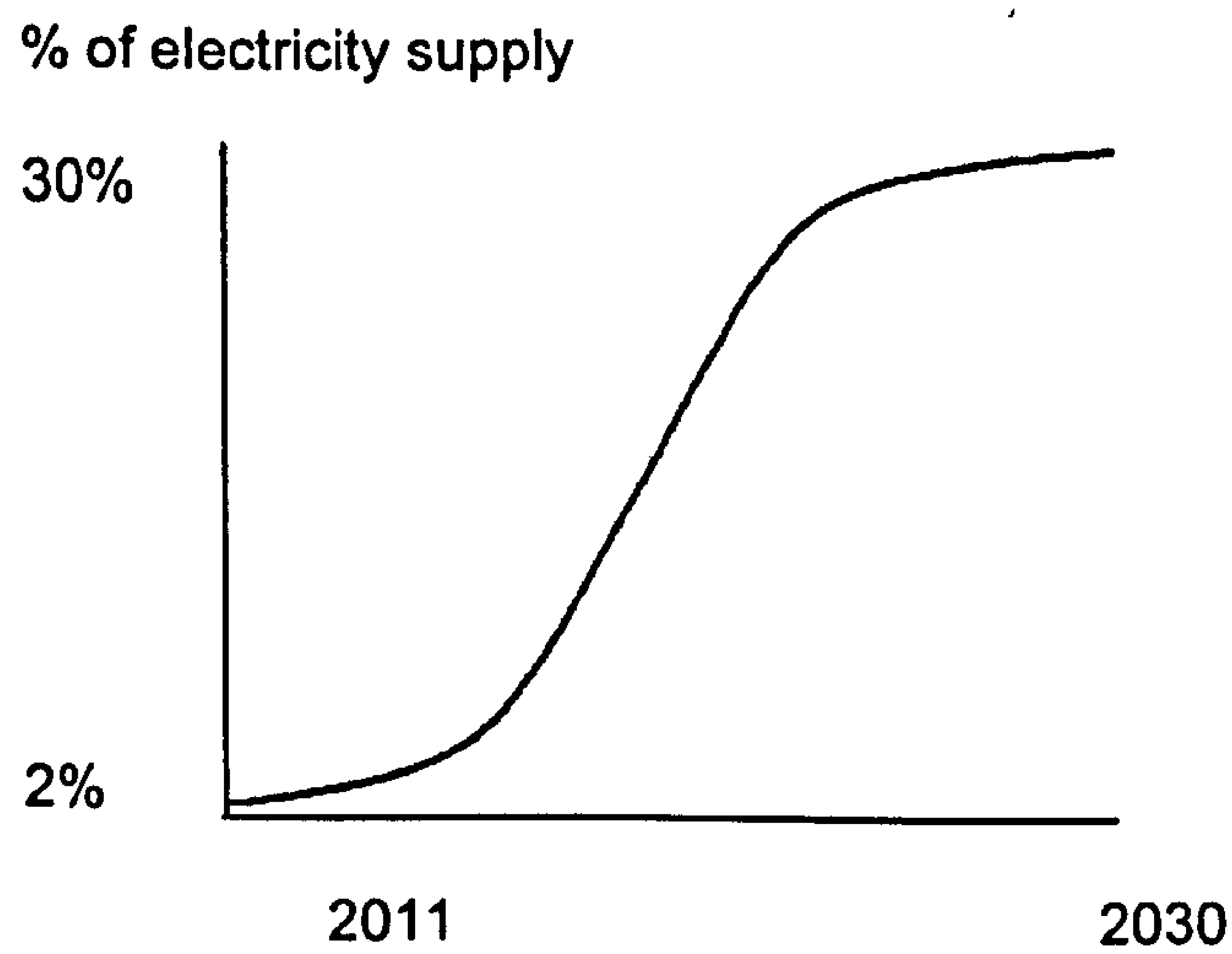


Figure 23 : SFV view of how growth of PV capacity in Germany should progress, from 2011 to 2030 (von Fabeck, 2011)

The industry minister Brüderle has two other PV related measures in his sights, as a press release from his ministry in February 2011 makes clear (BMWi, 2011). One is to bring PV systems within grid feed-in management, such that their output could be adjusted or switched off in the case that on sunny days it threatened grid management problems. This would apply only to systems with capacity of 100 kWp or more. However, once such a qualification to legally guaranteed grid access was made, it could act as the thin end of a wedge leading to similar control of smaller PV systems. The second measure is a reduction in the so-called "green electricity privilege" also provided for in the Renewable Energy Sources Law. It exempts from paying a share of FiT costs any electricity supplier which obtains at least 50% of its power from renewable sources. Brüderle proposes to limit the value of the exemption to €¢2.0 per kWh; in 2011 it is worth €¢3.5 per kWh.

6.2.9 Energy Concept

The government's Energy Concept, published in late September 2010 (BWi & BMU, 2010b), includes statements such as "In this Energy Concept, the German government has .... for the first time mapped a road to the age of renewable energy. The Concept is about designing and implementing a long-term overall strategy for the period up to the year 2050.". Those are liable to ring alarm bells among proponents of renewables, as they may imply a lack of urgency, or intention to stretch out the transition from fossil and nuclear energy over four decades. Target shares for renewables are as set out in Table 30 below.

Year	Target renewable energy share of gross final energy consumption	Target renewable energy share of gross electricity consumption
2020	18%	35%
2030	30%	50%
2040	45%	65%
2050	60%	80%

Table 30: German government targets for share of renewable energy, in its Energy Concept (BMWi & BMU, 2010)

The 18% target for final energy share in 2020 was agreed at EU level (EU, 2009). The actual shares as of 2009 were 9% of final energy from renewable sources, and 15.6% of electricity (BMWi, 2010b), so some acceleration is required to achieve the 2020 targets. After that, however, for the renewables share both of final energy and of electricity the progression is linear, not assymptotal. Moreover, the Concept includes a target of 25% reduction in electricity consumption by 2050, relative to 2008. That means that renewables shares will be of a smaller 'cake', with correspondingly smaller increases in absolute capacity.

Further potential ground for concern on the part of proponents of renewables expansion in Germany is in what the Concept says about sources of electricity in

2050. Wind energy is to "play a key role in electricity generation" ; but "expansion of German and European grids" is crucial ; and "on grounds of cost efficiency Germany will import a substantial share of its electricity requirement in 2050" (BMWi & BMU, 2010b, p.5). One interpretation of that combination of statements, juxtaposed in the same paragraph, is that imports of e.g. UK wind energy via European grids could account for much of the target share of renewables in Germany's electricity consumption - with correspondingly less installed capacity in Germany. In such a way, the established electricity industry in Germany could hold back domestic growth in renewables capacity, to protect and continue its operation of large scale fossil and nuclear power plants, while the government could still achieve its targets for share of renewables by importing electricity, decades from now. Why would that make sense? Perhaps by hobbling the growth of domestic renewables capacity as competitor to, and prospective supplanter of, large scale centralised electricity generation. In other words, to buy time during which the major electricity companies can realise profits on investments in plant.

On nuclear power, the Energy Concept says (ibid, p.14) that "the new nuclear fuel tax and other payments by plant operators will absorb the overwhelming share of additional profits, thus preventing economic betterment of nuclear power plant operators as a result of the extended operating lives.". The exact size of an "overwhelming" share is not specified; but it is difficult to see how any share less than 100% would prevent gain by nuclear power station operators. As noted in 6.2.6 above, the fuel rod tax is apparently to be deductible from other tax payments, which in itself gives some "betterment" to operators.

The Concept again refers to nuclear power as "a bridging technology", which "paves the way for the age of renewable energy" (ibid, p.15). Given that the Concept, as noted above, seems to place the threshold of the renewables age at 2050, does this mean that the 'nuclear bridge' stretches until that point? That would not be entirely consistent with government indications that the average nuclear operating lifetime extension is to be 12 years.

The need for Grid upgrading, including to accommodate an increasing proportion of electricity from decentralised sources, is recognised in the Concept (ibid, p.18). The target date for realisation is, however, once again 2050: a further indication of intention to stretch out the conversion to renewable energy supply? The large scale mindset is also again evident, in references to an "overlay grid" integrated into a Europe-wide "supergrid". The Concept envisages transmitting electricity from wind farms in the north, including offshore, to centres of electricity demand in the west and south of Germany. The west presumably includes the industrial and heavily populated Ruhr region, which is not very far from the north coast. Nor are demand centres such as Berlin and Germany's second largest city Hamburg. The south of the country possesses massive potential for PV, biomass and geothermal generation; so it is not clear how much need there should be for 'import' of electricity from the north. Unless the idea is to maintain large scale and centralised control of supply, through electricity company investment in GW scale offshore wind farms?

Further warning signs for the renewables sector, and PV in particular, may be discernible in references to integrating renewables into the market: "We will engage in a step-by-step process of preparing renewable energy sources for the market, transfer a growing proportion of renewables from support regimes under the Renewable Energy Sources Act (EEG) and into the market domain .... " (ibid, p.20). That echoes calls by the electricity industry for renewables to move "step by step out of the present subsidy model and be integrated into the market" (BDEW, 2010, author's translation). This may simply mean measures in the next biennial review of the EEG, due in 2011 with decisions to come into effect from1 January 2012, to give operators of already competitive wind farms flexibility to sell power directly on the market. On the other hand, it could indicate plans to find a way to dilute priority grid access for renewably generated electricity, without breaching the EU requirement to give renewables priority: see 6.2.10 below. Some adjustment of the feed-in tariff support mechanism will surely become necessary as renewables approach 'grid parity' (see 6.7 below).

Sharp criticism of the Energy Concept has come, as one would expect, from the Greens. Their energy spokesman Fell describes the Concept as, not an energy revolution, but a counter-revolution (Fell, 2010e). He accuses the government of having rigged the underlying scenarios to get the results it wanted, including in key assumptions and in the choice of institutes to elaborate the scenarios. Those are referred to in the published Concept only as "external experts"; but identified by the Industry and Environment ministries (BMWi & BMU, 2010a) as prognos in Basel, gws in Osnabrück, and the Energy Industry Institute at Köln University (German acronym EWI). Fell describes funding of €8m to EWI from electricity majors RWE and E.On as having made it into, in his view, their subsidiary.

Fell further states that the nuclear fuel rod tax is to be €145 instead of the proposed €220 per gram, and only payable for six years, yielding only €1.5bn in additional revenue. On top of that, the plan for energy companies to pay much of their windfall profits from longer operation of nuclear plants into a special fund for development of renewables and energy efficiency is only a 'declaration of intent', not a legally binding obligation. Accordingly, the government would have no power to compel payment should the companies withhold it. He believes that the government plans to give nuclear power priority in grid access, and in use of pumped storage facilties, which would be better suited to taking surplus wind and solar energy.

On PV, Fell's assessment is that the Energy Concept calls into question continuation of the feed-in tariff support mechanism once PV reaches grid parity, which the government expects to be at the latest in 2014 and possibly in 2012 (Fell, 2010e ; see also 6.7 below), such that the 2011 biennial review of the EEG might abolish the PV FiT. Another possibility as referred to above is a cap on the amount of newly installed renewables capacity eligible for support, perhaps as low as 1 GW annually. Fell (2011a) argues that a cap would replace market forces with bureaucracy and uncertainty as to whether and when a new PV installation would receive feed-in tariff support within the cap, adding to project costs and severely damaging investor confidence, leading to a collapse of the market as happened in Spain. Fell further observes that the slow pace of grid upgrading, that the government apparently has no plans to accelerate, also acts as a drag on build-up of renewables, as lack of urgent action on grid improvement to accommodate renewables would allow the established electricity industry and its supporters to continue to use grid integration difficulties as an excuse to hold back renewables (see also 6.6 below).

Environment minister Röttgen's claim that the German Wind Energy Association had welcomed the government's Energy Concept appears to be untrue, since the Association has stated (BWE, 2010a) that the Concept charts a wrong course for energy policy, is primarily for the benefit of nuclear plant operators, and would mean no further growth in onshore wind capacity after 2015. The Association also reports that the environment ministers of Rheinland-Pfalz, Nordrhein-Westfalen, Berlin, Bremen, Brandenburg, Hamburg and Saarland all oppose the Concept (BWE, 2010b).

Duffield (2009) predicts that energy security, in the last several years overshadowed by climate change, will once more become an important consideration in German energy policy. Despite the record of rapid growth, he questions whether renewables, together with increased energy efficiency, can achieve energy security, and relates the latter primarily to access to natural gas supplies. The Energy Concept states that: "The German government's goal is to ensure a high degree of energy security, including the primary energy sources of oil and gas." (BMWi & BMU, 2010b, pp. 28-31). It similarly gives most weight to securing access to foreign supplies, including of raw materials needed for energy technologies, linking transition to renewable energy rather to climate policy.

6.2.10 European Union policy

The EU continues to be supportive of build-up of renewable energy capacity, as a pillar of its climate policy. Companies have, perhaps predictably, complained that the policy to reduce carbon emissions would involve higher costs. The financial sector crisis and resulting economic problems which erupted in 2008 led to calls to dilute the emissions reduction plan. The then Environment Commissioner, however, opposed such dilution, given the imperative of action to combat climate change (reported in for example Grajewski, 2008).

Several years ago in a report on progress in renewable electricity, the European Commission called for immediate action to remedy unfair grid access, and declared that "The internal electricity market shall be developed in a manner consistent with the development of renewable energies." (Refocus Weekly, 2007). The PV Policy Group, coordinated by the German Energy Agency (dena) under the auspices of the EU Intelligent Energy programme, similarly called in 2007 for action on grid access for small decentralised PV, and for removal of any unnnecessary barriers (PV Policy Group, 2007).

The most recent EU agreement on promotion of renewables is the Directive adopted in April 2009 (EU, 2009). That sets a target for the EU overall of 20% of energy from renewable sources by 2020; the individual target for Germany is 18%. On renewable electricity, Article 16 of the Directive stipulates that:

"Subject to requirements relating to the maintenance of the reliability and safety of the grid, based on transparent and non-discriminatory criteria defined by the competent national authorities:

(a) Member States shall ensure that transmission system operators and distribution system operators in their territory guarantee the transmission and distribution of electricity produced from renewable energy sources;

(b) Member States shall also provide for either priority access or guaranteed access to the grid-system of electricity produced from renewable energy sources; "

The first sentence could could be interpreted by major electricity companies and their supporters as providing an escape clause. Their lines of attack against renewables already include alleged problems of integrating renewable, especially solar, electricity into the grid: see 6.6 below. The EU Directive also requires member States to develop their electricity grids so as to accommodate an increasing share of renewables; but that still allows scope to use claimed integration difficulties as a delaying tactic.

The established electricity industry might find further comfort in European Commission (2010), a communication about the "Energy 2020" strategy. It includes the statement that: "In the field of electricity generation, investments should lead to nearly two thirds of the electricity coming from low carbon sources by the early 2020s, the current level being 45%. In this context, priority should be given to renewable energies." Since preceding text includes nuclear power among "low carbon sources", the meaning of "priority" to renewables is open to varying interpretations.

As EurActiv (2010) reported, EU Energy Commissioner Günther Oettinger has called for a harmonised feed-in tariff mechanism in Europe for solar and other renewables. Oettinger, previously prime minister of Baden-Württemberg, said in July 2010 that the German EEG (Renewable Energy Sources Law) guaranteed "a fair price" for renewable energy, and that there ought to be a European EEG. The German government has, on the other hand, so far opposed any move to an EU-wide system. Environment minister Röttgen reiterated that position in January 2011, as reported in Enkhardt (2011b), and that the guarantee of grid access for renewably generated electricity must remain in place.

6.2.11 Wider policy perpectives

Sir Nicholas Stern has described "the rapid dissemination and use of low-carbon technologies" as "the only realistic future for growth and for overcoming world poverty" (Stern, 2009). He includes CCS among such technologies, without comment on its feasibility or timescale; and does not explicitly mention renewable energy.

Head of the UN Environment Programme, Achim Steiner, has expressed a similar view: "With world temperatures and fossil fuel prices climbing higher, it is increasingly obvious to the public and investors alike that the transition to a low-carbon society is both a global imperative and an inevitability." (Steiner, 2008). He puts greater emphasis on renewable energy as key element in that transition, as does the UNEP "Green Economy" report previously mentioned (UNEP, 2011). Mathews (2008) advocates the use of carbon credits to circumvent the objection of high upfront costs against rapid deployment of new technologies.

6.2.12 Outlook to 2020

Germany's national action plan for renewable energy, for submission to the EU as required under the 2009 Renewable Energy Directive (EU, 2009), was agreed by the Cabinet in August 2010 (BMU, 2010d). The government is confident of achieving the target of 18% renewables share of final energy, and expects even to exceed it. It forecasts in its action plan 19.6% share of final energy, and that renewables will supply 38.6% of electricity, well above the EU agreed target of 30% - also above the 35% target in the Energy Concept (Table 30 above). The action plan contains specific projections for PV, set out in Table 31 below.

Year	PV capacity added (MWp)	Total installed PV capacity (MWp)	PV electricity output (GWh)	Average array ouput (kWh/yr/kWp)
2010	6000	15,784	9,499	601
2011	4500	20,284	13,967	689
2012	3500	23,783	17,397	731
2013	3500	27,282	20,293	744
2014	3500	30,781	23,218	754
2015	3500	34,279	26,161	763
2016	3500	37,777	29,148	772
2017	3500	41,274	32,132	779
2018	3500	44,768	35,144	785
2019	3500	48,262	38,243	792
2020	3500	51,753	41,389	800

Table 31 : Projected growth of PV capacity and electricity output in Germany, 2010–2020 (source: national action plan for renewable energy; FRG, 2010)

As is apparent from the figures for annual growth of PV capacity, the German government in this action plan simply assumes new capacity of 3.5 GWp installed in each year from 2012 onwards. It is not clear whether that is based on assumed average annual growth with some fluctuations, an expectation of further cuts in incentives which will keep demand growth at around the 3.5 GWp level - or a planned formal cap on new PV capacity.

An interesting sidelight from the government's figures on PV, collected in Table 31 above, is that the implied average electricity output from PV arrays - simply the total projected output divided by total installed capacity - jumps from 601 kWh per year per kWp installed capacity in 2010 to 689 kWh in 2011, again to 731 kWh in 2012, and thereafter increases by a little over 1% each year. No explanation of this is apparent in the published action plan. The assumed annual output figures seem curiously low by comparison with PV array output projections from the PV Geographical Information System of the EU Joint Research Centre (PVGIS). They range from 1000 kWh/yr/kWp in Munich, through 877 kWh in Frankfurt, to 830 kWh in Essen ; even Flensburg on the Danish border is rated at 853 kWh. It may be that government assumptions are conservative, allowing for instance for sub-optimal array performance because of shading or orientation a little away from due south. The small annual increase from 2012-20 may reflect anticipated improvements in solar module efficiency ; or a preponderance of new capacity installation in areas with higher output ; or a combination of those effects.

The total projected PV output at 2020 accounts in the national plan for 19% of electricity from renewable sources (wind 48%, biomass 23%, hydroelectricity 9%). That is 7.3% of overall electricity supply (38.6 x 0.19), a substantial increase over PV's 1.1% share at the end of 2009 (BMU, 2010c), but involving a compound annual growth rate of only a little over 20% - well below what PV has achieved in Germany in the past decade.

Nonetheless, the outlook for continuing growth of PV in Germany is encouraging. Is it, however, compatible with the further cuts in feed-in tariff support and dilution if not removal of priority grid access of which opposition commentators such as Fell warn? Several scenarios are conceivable, as indeed are combinations of them:

- the German government genuinely wants PV to grow further, and is concerned only to avoid excessive returns on investment in it ;
- its strategy is to rely primarily on wind energy to meet commitments agreed in the EU context, and it expects to import wind generated electricity if domestic capacity growth is insufficient ;

- it plans to press for nuclear power to be recategorised as "renewable", or for the EU target to be changed from renewable to "low carbon" energy, including nuclear.

Further developments in relation to those issues in 2011, not least in the review of the Renewable Energy Sources Law, should be very interesting and shed light on the prospects for the next 5-10 years.

6.3 Criticisms of PV, and counterarguments

"There is nothing more difficult to take in hand, nor perilous to conduct, or more uncertain in its success, than the introduction of a new order of things, because the innovator has for enemies all those who have done well under the old conditions, and lukewarm defenders in those who may do well under the new."

Niccolò Machiavelli (1532), "The Prince", ch. 6

6.3.1 Introduction

Another dimension to the debate in Germany about promotion of PV is added by criticisms repeatedly levelled by certain organisations as well as politicians, and counter-arguments issued by supporters of PV.

The critical statements and reports have appeared frequently in the media, and recurrently contain the same few themes, briefly described below. The sources of criticisms are likewise small in number and recurring, prominent among them being : CDU and CSU spokespersons, the energy industry association BDEW, weekly magazine Der Spiegel, energy users association VEA, and the economics research institute RWI. Statements and reports seeking to rebut the critics' claims come principally from the federal environment ministry, the solar industry association BSW, the Greens, the renewable energy association BEE, solar promotion association SFV, and the DIW economics institute in Berlin.

Both the 'solar critics' and the 'solar supporters' evidently have interests as stake. Their respective motives may be surmised to be, on the critics' side preservation of the established large scale centralised model of electricity supply, and on the supporters' side transformation of the electricity supply as quickly as possible to renewable energy.

Sioshansi (2001) saw a trend in newly liberalised markets to "multi-utilities" supplying both electricity and gas, and towards consolidation of the industry into "megagenerators". The German market is dominated by the 'Big Four' major electricity suppliers: RWE, E.On, Vattenfall (Swedish owned), and En-BW (a subsidiary of France's EdF), which control 80% of supply. An indication of their scale is that in 2010 RWE's annual profits were approaching €10 billion.

Renewable energy, however, has also become important to the German economy in terms of employment, exports and regional development. Solar PV employed 64,700 as of 2009, as many as the coal and nuclear industries combined, and renewable energy in total 339,500. Renewables are predicted by 2020 to provide 450,000 jobs even in a conservative scenario (BMU, 2010e), in a similar league to Germany's much vaunted motor industry, with 723,000 employed in 2009 (BMWi, 2010a).

Is it to be expected that the established electricity companies will progressively switch to renewable energy? The late Hermann Scheer, whose doctorate was in economics, explained why not (Scheer, 2007): their investments in power plants and other infrastructure occur at various times, and have amortisation times measured in decades, so there will never be a point at which all investments have fully generated their expected returns. To switch to renewables would always mean some 'stranded investment', and loss of shareholder value. That is liable to motivate the companies to seek to continue the status quo indefinitely, and at least to delay the shift to renewable energy for as long as they can. It is necessary to bear in mind that a company is bound, by law in e.g. the UK, to maximise shareholder value and therefore to put the interests of its shareholders before anything else: it is ".... programmed to exploit others for profit. That is its only legitimate mandate." (Bakan, 2004).

Growth in renewable energy capacity to the extent that it provided a substantial proportion of Germany's electricity supply - meaning 35%, the German government's current target for 2020 (BMWi & BMU, 2010) - would obviously supplant a similar part of the established 'conventional' generation of electricity, even allowing for some demand growth which partly offset that loss of sales. Wind and biomass generating capacity can be owned and operated by utilities. PV, however, is largely small scale and decentralised. As Sawin (2007) predicted, "The conventional energy industry will be surprised by how quickly solar PV becomes mainstream - cheap enough to provide carbon free electricity on rooftops.". RWE recently announced (reported in Photovoltaik, 2010c) that it is getting out the PV business, because it does not offer efficient use of its capital; its aim is to "industrialise" renewable energy, which is consistent with the large scale centralised model.

6.3.2 Themes of criticism

"If you're a 'normal' person, you tend to believe any studies that support your current views and ignore everything else."

Adams (1996)

PV opponents in Germany put forward the following arguments, as reported for example in weekly news magazine Der Spiegel of 5 December 2009 (Der Spiegel 2009b) in an interview with Christoph Schmidt, President of the Rhine-Westphalian Institute for Economic Research (German acronym RWI, about which more below) and member of the "Five Wise Men" panel of economic advisers to the German government; and in Renewable Energy World (online) on 15 December 2009 (Blau 2009).

(a) The PV feed-in tariff (FiT) burdens electricity users with huge costs, which bear no rational relationship to the value of PV. Module prices fell in 2009 by approx. 30%; therefore so should the FiT. Manufacturers are making excessive profits.

(b) The projected cost in FiT payments for all PV arrays installed from 2000-2008, over 20 years as the EEG stipulates, is €35 billion. That figure would rise to €53bn by 2010. Yet PV generates only a tiny fraction of Germany's electricity.

(c) The increase in electricity tariffs announced for 2010 results from the cost of FiT payments, including the new "EEG Apportionment" system for dealing with the cost of grid transmission of renewably generated electricity.

(d) The FiT mechanism is economically very inefficient. The cost of it to electricity users reduces their purchasing power, with negative effects on consumption and employment.

(e) The EU Emissions Trading System sets a permitted level of overall emissions. Therefore any emissions reduction which results from PV capacity build-up is simply replaced by emissions elsewhere, and brings no environmental benefit.

(f) Better ways to reduce CO_2 emissions in electricity generation are to extend the operating lifetime of nuclear power plants, carbon capture and storage (CCS), and concentrating solar power from north Africa.

The following section briefly examines these criticisms, and the counter arguments put forward by PV supporters.

6.3.3 Criticism (1): PV support costs

The most frequently repeated attack against is PV is that the costs of supporting its growth through the feed-in tariff are enormous, and fast becoming an intolerable burden on electricity consumers. The critics call for deep cuts in the FiT, and more recently for dismantling of the Renewable Energy Sources Law and move to a "market based" approach to renewable energy promotion. Each claim has been followed swiftly by patient rebuttals, from the Environment ministry and others, including the points that electricity price rises are substantially greater than FiT costs could justify and that electricity companies are not passing on to consumers reductions in the cost of electricity on the Leipzig market (Bundesnetzagentur, 2010a; Enkhardt, 2010a). Those reductions are due in part to the previously mentioned "Merit Order Effect" of renewable generation, which largely offsets FiT support costs but which, if electricity companies can avoid passing it on, translates into extra profit (Sensfuß & Ragwitz, 2007).

A source of criticism of PV support costs in Germany often cited in the media, by politicans and by the electricity industry, is the previously mentioned Rhine-Westphalian Institute for Economic Research (RWI). RWI is in Essen - as is the head office of RWE, one of the "Big Four" electricity companies in Germany. The links between the organisations go deeper than the similarity of location and acronyms. The current President of the 'Friends and Supporters of RWI' is Dr Rolf Pohlig, the Financial Director of RWE; he took over the RWI role in June 2008 from Dr Dietmar Kuhnt, Chairman of RWE. The RWI website (www.rwi-essen.de/freunde-und-foerderer) states that the Friends and Supporters assist the Institute financially, and thus make possible activities which go beyond its base provision - which from the same website appears to be for basic research and "evidence based political advice". Those links not surprisingly prompt PV supporters to question whether RWI is simply a mouthpiece for the major electricity companies, putting a research institute veneer onto their attacks against PV.

RWI reports include some potentially misleading presentation of figures. For example, its position paper of April 2007 (Frondel et al, 2007a) gives as 'headline' figure the cumulative PV FiT costs over 20 years, but considers PV benefits only over a much shorter term. It also translates FiT costs into a "subsidy" of €108,000 (at 2005 prices) for each PV industry job, comparing that unfavourably with €70,000 per coal industry job in 2005 (Frondel et al, 2007b), but without clarifying that the PV figure is cumulative over 20 years whereas the coal figure is annual. A similar RWI report by Frondel et al (2009) once again highlights huge sums for PV FiT support, in this case "€77bn by 2013", without making clear that they are total commitments over the 20 year FiT lifetime.

As the Environment ministry's swift rebuttal (BMU, 2009b) said, the RWI criticism of the EEG renewable energy support law was "well known and refuted a long time ago". Neidlein (2009b) also set out cogent evidence countering RWI's presentation of the figures. That did not deter RWI president Schmidt, since March 2009 also one of the government's "Five wise men" economic advisors, from repeating the claims (Der Spiegel, 2009b). This time the alleged cost of FiT support for PV capacity installed between 2000-08 was put at €35bn "net". Net of what, in the RWI calculation, is not clear.

The federal Environment ministry calculates that Germany in effect makes a substantial 'profit', of approximately €6bn in 2009 (BMU, 2010f), by supporting renewables. That is the net balance of costs for FiT support, grid upgrade and transmission, versus benefits in avoided fossil fuel import costs, CO_2 emission savings and other environmental benefits. It does not include electricity cost reductions through the Merit Order Effect, nor employment and tax revenue benefits. Frank Merten of the Wuppertal Institute has pointed out that the success of PV, thanks in no small measure to the FiT, has made it possible to reduce the level of support sooner than expected (quoted in Westermann, 2008).

A point not so far noted in the PV supporters' arguments is that FiT costs for renewable energy, including PV, represent a supplement on electricity prices by which society collectively meets the cost of changing to the clean electricity supply essential to combat climate change. They are in effect no different from paying the higher cost for electricity which would result from factoring in externalities such as CO_2 emissions, pollution and health costs, in addition to rising fossil fuel prices. A further point is that FiT payments do not somehow disappear from the economy, but remain in it and add to the purchasing power of recipients. Indeed, "electricity consumers" viewed collectively receive as much in FiT payments as they contribute to them: so arguably there is no net cost.

The federal Environment Ministry issued in December 2009 an analysis of the effect of renewable energy support payments on the household electricity price (BMU 2009c). It states unambiguously that renewables are not, as repeatedly claimed, the driver of rising electricity prices. It presents (on page 8) a table showing that feed-in tariffs in 2009 cost domestic users on average 1.2€¢ per kWh (1.0¢ in 2007), and €3.50 per month on typical consumption of 3500 kWh/year (€2.90 in 2007); but as the grid retail price of electricity has also risen, from 20.7¢ in 2007 to 23.2¢ per kWh in 2009, the FIT share has remained at just 5%. Figure 24 overleaf shows the composition of the 2009 grid retail price. The solar industry association BSW points out that the new "EEG Apportionment" is merely a relabelling, and that "The costs have simply gone from one pot to another", not increased (quoted in Blau 2009).

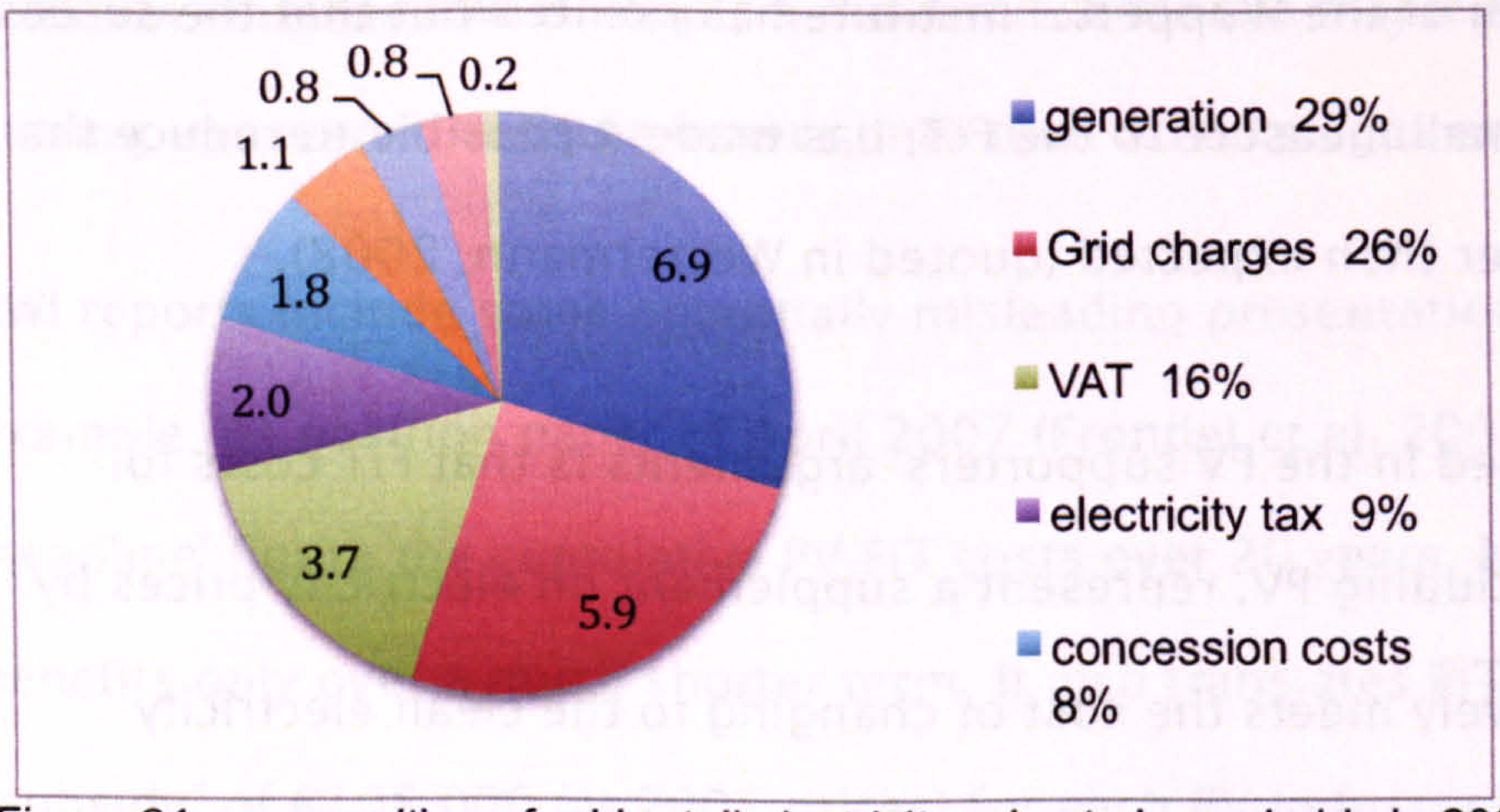


Figure 24 : composition of grid retail electricity price to households in 2009, in €¢ (total price = 23.2¢ per kWh). Source: Federal Renewable Energy Association, using data from electricity industry and Environment ministry.

An expert analysis commissioned by the Greens (Harms, 2010) concluded that the electricity price increase of 7.3% announced by RWE with effect from August 2010 was not justified. Falls in the spot market price should translate into a reduction of 0.1€¢ per kWh; instead, RWE was increasing the price by 1.5 €¢ per kWh. Electricity customers in Germany were paying altogether €1 billion more than they ought.

The Greens' energy spokesman Hans-Josef Fell rebuts critics' demands for a 30% reduction in the PV FIT because module prices dropped by 20-30% (Fell, 2009). The module price does not equate to the total system cost, of which about one third is "balance of system" consisting of inverters, mountings, installation work etc. Module prices need to fall by approximately 15% per year, estimates Fell, just to keep pace with the existing FIT taper. As the Environment ministry commented "It is .... evident that any analysis of renewable energy expansion which argues solely on the basis of costs falls well short of the mark." (BMU 2010f).

The conclusions of detailed analysis by Wenzel & Nitsch (2010), on the basis of PV capacity growth of 3.5 GW, per year from 2010-2030, include that projected cumulative differential costs of PV support over those 20 years are €71-91bn. That is less than RWI claim as the cost to 2020. Moreover, Wenzel & Nitsch seem to assume that the feed-in tariff mechanism will remain in its present form until 2030, which is not a given as PV reaches "Grid Parity" (see 6.7 below). They translate the cost to households of renewable energy support into a peak of €8 per month on the average bill, of which about half for PV. A survey in autumn 2010 by market research firm TNS Emnid found that 75% of Germans were ready to pay more to support solar energy, up to 2 €cents per kWh (BSW, 2010c).

No survey or opinion poll was seen which indicates that electricity users are unhappy about PV support costs, nor that acceptance of renewable energy has declined. If such evidence was available, one would expect PV critics to cite it.

6.3.4 Criticism (2): emissions trading means that renewables lead to no net reduction in CO_2

The argument, for example in Frondel et al (2007a), Panitz (2010), is that since the EU Emissions Trading Scheme allows companies to emit up to a given limit, reducing emissions in electricity generation by building up renewables capacity will simply displace those emissions to elsewhere, e.g. more coal-fired generation, within the limit. That would imply that the aim is only to stabilise emissions, not reduce them. Build-up of renewable energy needs to work in tandem with emissions cuts to combat global warming. Professor Claudia Kemfert of the German Institute for Economic Research (German acronym DIW) has pointed out that each successive negotiation about the level of CO_2 emissions certificates must take account of the reductions in emissions resulting from the growth of renewable energy capacity, in order to maintain the effectiveness of emissions trading (Kemfert 2009, DIW 2010), and not maintain a static level of emissions permits. RWE has acknowledged that full auctioning of emissions certificates will begin in 2013, which will increase costs to it as Europe's biggest CO_2 emitter (164.9m tonnes in 2010, an increase of 11% over 2009), though it will seek to pass the risk to electricity buyers (Eckert, 2011a).

6.3.5 Criticism (3): increasing PV capacity makes grid operation difficult

This issue is addressed in section 6.6 below.

6.3.6 Criticism (4): nuclear power is a bridge (or a barrier?)

The German government in late 2010 pushed through parliament an amendment to the law requiring phase-out of all nuclear power plants by 2021, extending plant operating lifetimes by an average of 12 years; that decision was the subject of legal challenge, and as noted in 6.2.8 above was suspended in March 2011 in view of the problems at the Fukushima plant in Japan. The government advanced the justification that nuclear energy is needed as a "bridge" into the renewables age. Green spokesman Fell (2010d) sees it differently, as "a massive barricade placed in [the] way" of the age of renewables. There is, however, a reasonable fit with German public opinion as surveyed in forsa (2009b): although 63% of respondents wanted the schedule for phase-out of nuclear power maintained or accelerated, 89% agreed with the proposition that older nuclear plants be closed earlier than planned, but younger (presumed) safer ones allowed to operate longer.

PV supporters point out that extending nuclear operating lifetimes means extra profit from already amortised plant: ".... to extend the lives of existing reactors .... is particularly important financially, because once you've paid for the reactor, additional years are very lucrative...." (Grimes, 2010). As noted earlier, the major electricity companies which operate the nuclear plants are to give up a proportion of that extra profit in tax, but will still make gains.

Of major concern to the PV supporters are calls to remove the priority grid access for renewably generated electricity guaranteed under the Renewable Energy

Sources Law (EEG). Loss of that guarantee would be a major blow to the prospects of renewables capacity growth. As discussed in 6.2.10 above, the EU Directive of April 2009 appears to safeguard priority grid access for renewables; but leaves scope for claims of grid management problems, on the basis of which utilities could seek at least partially to block feed-in of PV and other renewable electricity. FiT income would in that case fall, making PV systems no longer financeable or the projected return on investment insufficient. Simply the risk of that happening would probably be enough to reduce build-up of new capacity.

Mitchell & Woodman (2006) concluded that nuclear power undermines other low carbon technologies, not least renewables, and is therefore not complementary to them. If there is on the grid too much non-dispatchable capacity, which includes nuclear and many renewables, when demand is low some of it must be shut down and therefore earn no income - which is not attractive to potential investors (Skea, 2009). A further point is that if nuclear electricity displaced renewables, that would mean an increase in CO_2 emissions, since they are higher from nuclear power than from e.g. PV or wind energy (Sovacool, 2008).

6.3.7 Electricity supply gap?

The nuclear lobby maintain that unless more plants are built "the lights will go out" because of an electricity generation gap in 2015-16, resulting from the shutdown of coal-fired plant under the EU Major Combustion Plant Directive, in addition to closure of nuclear plants under the phase-out programme: a total of 15 GW of capacity by 2015, and a further 5 GW in 2015-20.

Other publications have rebutted that claim, including the 2008 monitoring report by the federal economics ministry on security of electricity supply, described in BMU (2008). A 2008 study by the German energy agency (dena) purporting to find risk of a supply gap was shown by a counter-study, commissioned by Greenpeace Germany (Steffens, 2008), to be based on false assumptions: electricity demand higher and renewables share lower than German government targets, and the load factor of conventional power stations higher than achieved to date. After correcting for such errors, no risk of a supply gap is apparent. Analysis in 2009 by the German renewable energy association (BEE, 2009) concluded that on the basis of conservative assumptions, there would still be enough generating capacity in 2020 to meet peak demand, helped by expected increases in pumped storage and in dispatchable biomass capacity. A report in that year by the federal Environment Agency (Klaus et al, 2009) similarly argued that the 'supply gap' is a phantom, and that no new conventional power station without CHP is necessary up to 2020, even if the nuclear phase-out proceeds as planned.

6.3.8 Criticism (5): carbon capture and storage is a better answer

The presently electricity supply system depends heavily on coal- and gas-fired generation. The International Energy Agency's 'World Energy Outlook' 2010 continues to predict that "fossil fuels - mainly coal and natural gas - remain dominant" to 2035 (IEA, 2010a). Carbon capture and storage (CCS) is advocated as the way to square that with the need to reduce carbon emissions.

The head of the IEA Clean Coal Centre is, as one might expect, a proponent of CCS. He recognises that it may not be economically viable until 2025, and expects governments to create "mechanisms for helping it through the next ten years" (Topper, 2008), including underwriting cost and risk. He thinks that "governments will grant permissions for unabated coal plants and then set deadlines for when CCS has to be fitted, perhaps ten years from now". So the prospect is that coal (and gas) fired power plants continue to emit CO_2

throughout this decade, in anticipation that CCS equipment will then stop the emissions. There seems to be little if any consideration of the downside risk, that the technology might not function as expected.

Electricity companies appear to be reluctant to meet the cost of CCS demonstration plants, generally estimated at €1 billion per power plant (see for example Harrison, 2008), with a reduction in plant efficiency and output to boot. A more specific example is a 450MW coal fired plant proposed by RWE near Köln, with a price tag including full CCS of €2 billion (Welchering, 2009). Analysis by researchers at Landesbank Baden-Württemberg reported in Welchering (op cit) found that for replacement of an old gas fired power plant, PV would cost considerably less than CCS. Moreover, it is of course available now. "Today, this idea [CCS] is being used as a justification for building new coal-fired power stations, with the promise that in maybe 15 years the carbon could be captured. These promises won't be fulfilled. In any case, carbon capture would cost much more than renewables, so why bother?" (Scheer, 2008b).

6.3.9 Criticism (6): Desertec is another better answer

Critics question the wisdom of incurring high costs to promote PV in relatively cloudy Germany, and advocate instead generating solar energy in sun-drenched north Africa. A consortium of mostly German companies proposes to build concentrating solar power (CSP) stations there, using the Sun's heat to drive turbines to generate electricity; it is not PV. Projected output would be equivalent to 15% of Europe's electricity demand, at initial estimated cost of some €400 bn (e.g. Connolly, 2009).

PV supporters are not convinced , pointing out that renewables already generate 16.3% of Germany's electricity (BMU, 2010c) - hardly the "inefficient niche technologies" referred to by the head of the Association of Energy Users (Panitz, 2010). Scheer (2009) saw it as akin to the "nuclear as bridging technology" line, aimed at putting off action to build renewable energy, in the hope of a large scale solution just over the horizon.

Desertec is also a long term project, as the chairman of the Desertec Industrial Initiative acknowledges (van Son, 2010), to begin with a mere 600 MW capacity through the Morocco-Spain interconnector, as many countries in the region lack the ability to transmit electricity to Europe for want of grid connections. The new German government's national action plan on renewable energy submitted to the EU (FRG, 2010) acknowledges that "In contrast to PV, concentrating solar power will in 2020 still make no contribution worth mentioning to electricity supply in Germany." (author's translation). For a thorough and detailed analysis of the Desertec proposal, see Paulitz (2010). Adding to the risk are recent developments in Tunisia, Egypt, Algeria and not least Libya. They may lead to democracy and greater stability in the region; but the outlook is far from certain.

6.3.10 Conclusions

The first half of 2011 could be a critical period in terms of the prospects for continuing PV growth in Germany. The removal of guaranteed priority grid access would be a serious setback; as would imposition of a cap on annual capacity growth eligible for feed-in tariff support, as experience in other markets, notably Spain, has shown.

The political situation is, however, fluid. Elections to regional parliaments will take place in several Länder, and their outcomes could put pressure on Chancellor Merkel to moderate measures to reduce PV support costs and to eschew a capacity growth cap or the ending of priority grid access. Attention is focused in particular on the election in Baden-Württemberg on 27 March. Its results will be just too late for inclusion in this thesis. Latest Emnid polling as at 20 March (LPB, 2011) has government and opposition very close: CDU 38% + FDP 6%, versus SPD 22% + Greens 25%, with Die Linke on 4% and "others" on 5% in total.

The following sections of this chapter will address in a little more detail the outlook with regard to growth of demand for PV in Europe and globally; and to the development of the PV industry, technology and costs.

6.4 : Demand for PV

"Solar energy is not an 'alternative energy'. It is the original and continuing primary energy source. All life and all civilizations have always been powered by solar energy."

Aitken (2003)

6.4.1 Introduction

This section will review, for Germany and other markets:

(i) recent forecasts of demand for PV, and actual increase in capacity ;

(ii) predictions for overall demand up to 2020 ; and

(iii) prospects in segments of the PV market, in particular small rooftop systems.

6.4.2 Previous forecasts

"Prediction is very difficult, especially about the future." (attributed to Niels Bohr)

More than a decade ago, Oliver & Jackson (1999) projected the 40% annual growth rate of PV to lead to global demand of 9.525 GWp in 2010. The European Photovoltaic Industry Association forecast (EPIA, 2006) a *global* market for PV of 5.4 GWp in 2010, and that was in an "accelerated" scenario. Rogol estimated global demand at 5 GWp in 2010 and 20 GWp by 2015 (quoted in Stauffer, 2005). Hoffmann (2008) presented a range of forecasts for global PV demand in 2010, as in Table 32 below.

Projection by	Demand in GWp
EPIA, Xmas workshop December 2007	4.7 – 7.0
Landesbank Baden-Württemberg, January 2008	15.0
Navigant Consulting, August 2007	4.0 – 8.3
Bank Sarasin, November 2007	8.0
Deutsche Bank, July 2007	9.0

Table 32 : Projections of global PV demand at 2010. Source: Hoffmann, 2008

The prize for accuracy goes to Landesbank Baden-Württemberg (LBBW), as Wynn (2011) reports EPIA estimates of 16 GW of new global capacity installed in 2010.

MITRE (?2003) reported modelling outputs of 1.046 GWp for PV in Germany at 2010, and 2.459 GWp at 2020. Porter & Rogol (2008) foresaw PV demand in Germany and Japan together in 2010 as only 25% of global production. Professor Hausladen of the Technical University of Munich expressed the opinion (Hausladen, 2004) that the real breakthrough for PV would not occur for 10-20 years, meaning in the period 2015-25. EuPD Research (2008) expected a decrease in feed-in tariff rates to slow demand in Germany from 2009. Developments since then show these predictions to have been very conservative. New PV capacity installed in Germany in 2009 was 3806 MWp, over six times the 635 MWp growth in 2004 , and total cumulative capacity stood at 9.8 GWp (Bundesnetzagentur, 2010a). Forecast growth in 2010 was 7.4 GWp (Bundesnetzagentur, 2011).

The German renewable energy agency in 2009 analysed 50 previous forecasts of renewable energy growth in Germany, Europe and worldwide, and found that almost all of them proved to be too conservative, in many cases by a wide margin (Pieprzyk & Rojas Hilje, 2009). EPIA and Greenpeace likewise point out that actual PV market growth has been faster than their "Solar Generation" series of reports predicted (EPIA & Greenpeace, 2010).

The most prominent understater of potential is arguably Dr Angela Merkel: "It is hardly realistic to increase the share of renewable energy in electricity supply to 20%. I believe that it is unrealistic to expect renewables to fill a supply gap arising, for example, from the early phase-out of nuclear power." ; in speech to congress of the German electricity and water industry, 8 May 2005 in Berlin, quoted in Pieprzyk & Rojas Hilje, 2009 (author's translation). By the end of 2009, renewables had already reached a share of 16.1% of Germany's electricity generation (BMU, 2010b), an increase of 0.9% over 2008.

6.4.3 Forecasts for the near term, and up to 2020

6.4.3.1 Germany

LBBW's crystal ball had apparently clouded somewhat by 2009, when they predicted PV growth in Germany of 2.225 GWp in 2009, 2.515 GWp in 2010, and 2.512 GWp in 2011 (Seeliger, 2009). By contrast, iSuppli forecast PV demand in Germany of 9.5 GWp in 2011, dropping over subsequent years into the 4-5 GWp range annually, within an "orderly progression towards its ultimate goal of about 80 GW of installed PV capacity by 2028" (Wicht et al, 2010). Since their forecast of *global* new PV capacity (Wicht, 2010b) is 13 GWp in 2011, 20 GWp in 2012, and 30 GWp in 2013 it would seem that they expect Germany still to account for the majority of growth.

EPIA (2010a) predict that the measures taken by the German government in 2010 to reduce PV support - supplementary in-year cut of 16% in the feed-in tariff for rooftop systems, and "corridor" provision for possible higher degression rate in case of higher new capacity installation in the preceding year - will "considerably affect the market in the coming years". They forecast 5-7 GWp of new capacity installed in 2010, then 3-4 GWp annually from 2011, possibly stabilising in the 3-5 GWp range from 2014 onwards.

Wenzel & Nitsch (2010) projected PV capacity growth in Germany of 6 GWp in 2010, 4.5 GWp in 2011, and 3.5 GWp annually thereafter. EuPD Research regard 6 GWp growth in 2011 to be "not improbable"; while iSuppli's latest prediction is hardly changed at 9.4 GWp, with a slow start followed by a very strong second half year (Danger, 2011).

A study by the German Aerospace Centre (DLR) in 2008 concluded that the share of renewables in electricity generation in Germany could reach 30.4% by 2020 (Nitsch, 2008). BEE (2010a) put the achievable share at 47%, with PV providing 7%, namely 19.5 TWh out of 278 TWh total supply needed after energy saving measures. The view of Büsgen & Dürrschmidt (2009) is that "a renewables share of more than 30% of electricity consumption by 2020 seems quite realistic".

Scenarios modelled by Henze (2007) demonstrate that assuming an annual growth rate of 40.9% in new PV capacity installed, and 21.8% for wind energy, renewables could supply 100% of Germany's electricity by 2020. In that case PV generates 240 TWh annually. His analysis is based on technical potential, and evidently assumes no constraints of grid integration or energy storage. PV capacity grew at a compound annual rate of 42% from 1974 to 2009 (Mints, 2010b).

The timescale fits with that foreseen by the Saudi oil minister Sheikh Yamani in 1981, quoted in Leggett (2005, pp. 148-9): ".... if we force Western countries to invest heavily in finding alternative sources of energy, they will. This will take them no more than seven to ten years....". As Leggett points out, if we could have done it then in 7-10 years, we certainly can now.

Professor Weber, head of the Fraunhofer Institute for Solar Energy, predicted in 2007 that the PV market in Germany, growing at 40% per year, would increase to 100–150 GWp within 5-10 years (quoted in The Guardian, 2007). A study by

Roland Berger and Prognos for the solar industry association envisages installed PV capacity in Germany reaching 52-70 GWp in 2020, with annual growth from 2012 at 3-5 GWp (reported in Photon, 2010a).

6.4.3.2 Other markets, and global

The European Photovoltaic Industry Association (EPIA, 2010a) expected new global PV capacity installation in 2010 of between 10.1 GWp under its 'moderate' scenario, and 15.5 GWp under its 'policy driven' scenario, the latter producing 30 GWp growth in 2014. The 2010 figures were revised upwards from EPIA's earlier forecast of 8.2-12.7 GWp. However, forecasts by EPIA in 2009 of PV capacity growth in Germany (Cameron, 2009a) have already proved very conservative: between 2-2.5 GWp in 2009 (actual outturn was 3.806 GWp), and 2-2.8 GWp in 2010 (estimated outturn 7 GWp). They forecast 2.3-3.2 GWp for 2011, 2.6-3.6 GWp for 2012, and 3-4 GWp for 2013.

IHS Emerging Energy Research foresee average annual capacity growth in Europe of 5 GWp from 2010-2012 (reported in Renewable Energy Magazine, 2010).
The view from prominent PV market analysts Navigant Consulting is that "2011 should also be a year of strong growth, if for no other reason than the capacity is there, production will continue and product will be shipped, even at a loss." (Mints, 2010c); adding, however, that "the next significant market for solar is difficult to identify at this juncture.".

IMS Research (Sharma, 2010) also consider that demand will probably be brisk in 2011, but warn of uncertainty owing to the interplay of several factors. Would-be buyers of PV systems will anticipate that the 2011 review will substantially cut the feed-in tariff as from the beginning of 2012, so want to install before then. They may well, however, also expect prices to fall during 2011 because the industry is building up production capacity, which is likely to lead to over-supply of modules; and therefore defer purchase, causing a short term drop in capacity growth. The potential further FiT cut from July 2011 might on the other hand pull forward some demand.

Link & Wheelock (2009) estimate the *global* market for distributed PV, defined as systems of less than 20 MWp, as just 3.6 GWp in 2008, and forecast annual growth of 22% to 9.7 GWp in 2013. That would appear questionable, since according to the German solar industry association (Stryi-Hipp, 2009), MW scale PV systems accounted for only 10% of capacity in Germany, which by itself had reached 9.8 GWp at the end of 2009.

EPIA's "Set for 2020" study (EPIA, 2009) sets out three scenarios for deployment of PV in the EU plus Norway and Turkey. The business as usual 'baseline' (or 'reference') scenario envisages PV generating 4% of electricity supply in 2020 ; the 'accelerated growth' scenario 8% ; and the 'paradigm shift' scenario 12%, requiring rapid increase in energy storage and smart grids. EPIA & Greenpeace (2010) give worldwide projections of total PV capacity installed by 2020: see Table 33 below.

2020 in GWp	OECD Europe	North America	India	China	other Asia	OECD Pacific	*World total*
Reference scenario	30	16	1	8	2	13	*77*
Accelerated scenario	140	77	20	29	19	31	*345*
Paradigm shift scenario	366	145	33	38	24	33	*688*

Table 33: projection of total installed PV capacity by region in 2020 under three scenarios. Source: "Solar Generation 6", EPIA & Greenpeace, 2011

Those forecasts are a good deal more positive than the FORRES study in 2005, which envisaged PV generating only 0.5% (17.9 TWh) of Europe's electricity in

2020, even in its "best practice policy" scenario (Ragwitz et al, 2005), with solar thermal electricity, i.e. CSP, at 0.6%.

Professor Edenhofer of the Potsdam Institute for Climate Research expects PV to grow considerably and to provide a significant share of electricity supply from 2020, because from then the carbon price will rise and make renewable energy relatively cheaper (Vorsatz, 2009). Dr C. Gay of PV equipment manufacturer Applied Materials envisages annual global PV capacity addition reaching 163 GWp in 2020, under a "paradigm shift" scenario which, however, involves just 34% annual growth rate. His projections including intermediate years are in Table 34 below.

2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
13	18	26	37	52	65	82	103	129	163

Table 34: Projected annual global PV installation in GWp, at 34% growth rate (source: Gay, 2010)

Bank Sarasin of Switzerland predicts a very similar level of annual capacity growth in 2020, at 155 GWp, based on economic factors working in favour of the PV industry (Bank Sarasin, 2009). iSuppli's forecast quoted in Electroiq (2010) was 19.3 GW in 2011.

The EPIA & Greenpeace 'Paradigm shift' scenario is consistent with Resch et al (2008), who foresee PV providing 4.4% of global electricity supply in 2020, on the basis of IEA scenarios; and with Peter & Lehmann (2008), who project a PV share in global electricity supply in 2030 of approximately 9% in their low growth scenario, or 13% in the high growth scenario, with installed capacity of 258 GWp or 701 GWp respectively. Based on the IEA (2008) forecast of 30,000 TWh global electricity demand (common to all scenarios), Behrendt (2008) equated a 5% share of electricity supply in 2030 with installed capacity of 1250 GWp, requiring a compound annual growth rate of 20.8%.

By contrast, the IEA Solar Photovoltaic Roadmap (IEA, 2010b) assumes only 17% annual growth rate to 2020, then 11% to 2030, reaching 11% of world electricity supply by 2050. Global installed capacity would reach 200 GWp by 2020, and 900 GWp by 2030. The IEA's "BLUE Map" scenario for halving CO_2 emissions by 2050 relative to 2005 envisages renewables providing only 17% of the reduction, less than carbon capture & storage at 19% (IEA, 2010c). The European Climate Forum's "Roadmap 2050" for decarbonisation of electricity supply (ECF, 2010) also includes CCS in each of the three pathways it analyses, along with 200 GW of new nuclear capacity in the "40% renewables" pathway or replacement of half of current nuclear plant with 80% renewables. However, it also acknowledges that: "While the three main pathways employ some quantity of nuclear and coal-with-CCS plants operating in customary fashion, neither nuclear nor coal-with-CCS is necessary to deliver decarbonization while maintaining the current standard of reliability (.... with the 100% RES being fully reliable) " (ibid, p.11).

Investors surveyed at Cleantech Forum XII in 2007 saw solar power as likely to contribute most to global energy supply by 2020, in view of its rapid growth rate (Renewable Energy Access, 2007). The 2007 "Clean Energy Trends" report from consultants Clean Edge predicted that the solar power market would grow to $69bn by 2016, four times its 2006 level (ReFocus, 2007). The then Director of the International Renewable Energy Agency expressed a similar view: ".... PV will play a more important role in the future - simply because costs of the equipment are very likely to continue coming down considerably." (Pelosse, 2009).

The huge fund management company Fidelity Investments sees PV as a massive growth industry, and predicted (Collinson, 2008) that PV would achieve grid parity in Spain by 2011. That is in line with the prediction in 6.7.2 below of grid parity in Germany as a whole in 2013, taking the FiT rate as proxy for average PV cost per kWh.

Bloomberg New Energy Finance expect annual global investment in renewable energy to increase from $90bn in 2009 to $150bn in 2020, and $200bn in 2030; primarily in onshore wind energy, but also with significant expansion in PV (PEI, 2010b). Munich based consultant Johannes Spannagl predicts (Wieselhuber & Partner, 2009) that Germany's share of the world PV market will decline greatly by 2020. See also Roland Berger Strategy Consultants (2010) on other markets, especially China, USA, and India.

6.4.3.3 Emerging markets

Mints (2009) observes that "The global solar industry cannot continue expecting Germany to save it ....", adding that "Europe will continue as the major market for solar products for some time, and Germany will continue as the stable leader of this movement. But the rest of the world has a responsibility to make similar commitments.". There are numerous indications that the rest of the world will play its part in building up PV capacity towards the levels forecast in 6.4.3.2 above. IMS Research has identified 18 markets which it expects to install at least 100 MWp of new PV capacity in 2011: Italy and the US at GWp level, with other markets in eastern Europe and Asia (Photovoltaics World, 2010a). Lux Research (2010) see India as having the greatest long term potential, with Israel, Malaysia and South Africa providing "pockets of short-term demand".

The UK is a new market, following the introduction of a feed-in tariff from April 2010 in England, Scotland and Wales. Pöyry (2009) estimates the technical PV resource in Great Britain at 60.4 TWh per year, at an average projected system output of 860 kWh/kWp installed capacity, implying potential capacity of 71 GWp. Initial forecasts of PV demand in the UK market in 2013 range from 500 MWp of cumulative installed capacity (PWC, 2010a), to *annual* new capacity of 510 MWp (iSuppli, reported in Photovoltaics World, 2010b) or between 280-650 MWp (EuPD

Research, 2010b). Plans have been announced for MW scale ground based PV arrays totalling perhaps 1 GWp of capacity by 2015 (Elliott, 2010b); but proposed cuts in FiT rates for larger systems may undermine them (DECC, 2011).

Other markets in Europe which have attracted regular attention are **Spain, Italy** and **France.** It is difficult to pin down forecasts of growth over the coming few years, as cuts in feed-in tariff rates have caused a state of flux. One forecast for Spain is 375-500 MWp annually up to 2013, following 600 MWp growth in 2010 (Cameron, 2010b). That is consistent with the Spanish government's target of 8.673 GWp total installed capacity by 2020 (Castano, 2010). Italy's national plan sets a target of 8 GWp by then. France's national plan target is 4.860 GWp, and Greece's is 2 GWp (Ristau, 2010). Italy became a GW market in 2010: the conservative preliminary forecast for new capacity installed was 1.85 GWp, with at least 3.2 GWp more in the pipeline awaiting registration (Photon, 2011a). Wynn (2011) puts capacity growth in Italy in 2010 at 3 GWp. Its solar industry association GIFI predicts growth of 5 GWp in 2011 alone, with total installed capacity reaching 15 GWp by 2015 (Kovalyova, 2011). Reports are, however, emerging of government action to restrain growth. In late February 2011, the French government placed a cap of 500 MWp on annual PV growth, with the possibility of increasing it to 800 MWp after a review in 2012 (Photon, 2011b). It is not yet clear whether that will lead to a market collapse, as happened in Spain.

The outlook in the **USA** has improved since Menz (2005) noted projections that the non-hydropower renewables share of electricity output would grow only from 2.1% to 3.3% by 2025, with PV a neglibly small component of that. There are increasing signs that the "sleeping giant" is awakening. Before his election, President Obama pledged to support rapid growth of renewables, with the focus on wind and PV, investing $150 bn over ten years (reported in Kirschbaum, 2008b). The prospects of action at the federal level are uncertain, especially following Republican gains in the mid-term elections of November 2010. However, a succession of States have taken positive action, such as California, Pennsylvania, Ohio, Vermont, New York and Texas (Herron, 2009). Public support would appear from a 2008 survey to be strong (Schott Solar, 2008). The potential is great. Stodola & Modi (2009) estimate that almost 200 GWp of PV capacity could effectively supply electricity without need for storage. Moreover, the potential could be realised quickly since many parts of the USA have insolation levels which could enable early achievement of grid parity (see 6.7 below). As SolarWorld CEO Frank Asbeck said (quoted in Kirschbaum, 2008), ".... when that happens, the demand will soar. There will be no limit to the growth.".

New PV capacity installed in 2009 was 450 MWp, and the forecast for 2010 is around 900 MWp, as reported by Opalka (2010), who also notes a prediction by GTM Research that the USA will by 2015 be world leader in annual capacity installation. Market research firm Solarbuzz forecasts that total capacity will grow to 4.5-5.5 GWp, at an annual growth rate of 30% (Photovoltaics World, 2010c). GTM Research predicts market demand in 2012 of 2.13 GWp, making the USA the world's no.2 PV market after Germany (Wang, 2010).

Another potential giant, which began stirring several years ago, is **China**. The National Development and Reform Commission has set a target for PV capacity to reach 1.8 GWp in 2020 (Solar Plaza, 2009). That seems modest for such a large country, slightly less than Greece's goal. It is also sharply at odds with EPIA's forecast that "China and India are also expected to boom in the next five years with huge market potential and impressive projects in the pipeline." (EPIA & Greenpeace, 2011), and of at least 8 GWp installed by 2020 (Table 33 on p.224 above). A positive development is the 2009 update of the 2005 Renewable Energy Law, described in Martinot & Li (2010). Its provisions include guaranteed purchase of PV electricity by utilities, and the "Golden Sun" programme of incentives albeit only for PV systems of 300 kWp or larger capacity. In addition, some provinces have introduced preferential tariffs for PV electricity.

An established market, whose performance has however stuttered, is **Japan**. As long ago as 1994, its government set guidelines for PV capacity growth, to reach 4.6 GWp in 2010 (Kuwano, 1998). The report "Energy Rich Japan", described in Lehmann & Peter (2004), outlined six scenarios for 100% renewable energy supply, including at least 60 GWp of PV. As at 2008, PV capacity stood at 1.4 GWp; the Japanese government agreed targets of 14 GWp by 2020, and 53 GWp by 2030 (Kaizuka & Ikki, 2009), and reintroduced a subsidy for PV installation on house roofs along with a feed-in tariff for surplus PV electricity, and substantial R&D investment. A somewhat unusual structural factor should assist the growth of PV on house rooftops: the tendency of the Japanese to rebuild their houses on an approximately 25 year cycle. That fits well with the operating lifetime of PV systems, and as noted earlier enables house builders to offer PV as a standard option included in mortgage financing.

Another potential Asian giant is **India**. Its "National Solar Mission" determined in 2010 sets a PV capacity target of 20 GWp by 2022 (Dayanandan & Kamp, 2010). Its government is also supporting the development of a major PV manufacturing industry (Malaviya, 2008).

Reports of further new national PV markets appear at frequent intervals. As reported in Neidlein (2010), the Swiss Bank Sarasin expects at least ten new PV markets, each with annual new capacity demand of over 500 MWp, to become established. Candidates for future growth include China, India, Greece, South Africa, Bulgaria, Brazil, Ontario, South Korea, Turkey and Australia, in addition to the existing major markets of Germany, France, Italy, Spain, Japan and the USA (which itself comprises a number of State markets, e.g. California and Texas).

Beyond that, there exists potential to deploy PV virtually everywhere on the planet. Its modularity and scalability from a few hundred Wp to MWp systems make it ideally suited to off-grid applications in less developed countries, giving access to electricity to the nearly 1.5 billion people who lack it (IEA, 2010c). The principal off-grid PV markets are identified in Schmidt (2009) as South Africa, Uganda, Botswana, Morocco, Thailand, India, Philippines, China, Chile, Mexico and Peru. EPIA (2010b) identifies considerable potential in high insolation "Sunbelt" countries: 405 GWp capacity by 2030 under an 'accelerated' scenario, and as much as 1100 GWp under a 'paradigm shift' scenario.

6.4.3.4 Forecasts for the longer term

EPIA & Greenpeace's "Solar Generation" report, issue 6 (EPIA & Greenpeace, 2011) presents six scenarios for PV's share of global electricity generation up to 2050, as set out in Table 35 below. The wide variation, with highest PV shares 10-15 times the lowest ones, illustrates both the conservative view of the IEA on PV growth potential and the importance of energy efficiency measures in achieving a high proportion of renewables in energy supply.

Reference: IEA projection of PV market growth	**2020**	**2030**	**2040**	**2050**
share of electricity output - IEA projected demand	0.4%	0.7%	1.1%	1.4%
share - demand reduced by energy efficiency	0.4%	0.8%	1.3%	1.8%
Accelerated PV market growth				
share of electricity output - IEA projected demand	1.9%	4.9%	8.2%	11.3%
share - demand reduced by energy efficiency	2.0%	5.7%	10.1%	14.0%
Paradigm Shift PV market growth				
share of electricity output - IEA projected demand	4.0%	7.8%	12.6%	17.1%
share - demand reduced by energy efficiency	4.2%	9.1%	15.5%	21.2%

Table 35 : PV share of world electricity consumption under various scenarios of PV market growth rate and projected electricity demand. Source: "Solar Generation" 6, EPIA & Greenpeace (2010).

The highest share in 2030, 9.1%, corresponds to PV generation of 2260 TWh from 1845 GWp installed capacity ; that in 2050, 21.2%, to generation of 6750 TWh from 4670 GWp capacity. The estimation of the Photovoltaic Technology Research Advisory Council for the European Commission (PV-TRAC, 2004) was that in 2030 PV could provide 4% of global electricity supply, and continue to grow steadily thereafter.

US consultancy firm Lux Research predict that PV capacity will grow over decades, and "wildly beat its expectations in the long term" (Renewable Energy World, 2010). Lux expect adoption of PV to rely largely on replacement cycles for residential and commercial building roofs, and for natural gas power plants. Analysis by Lund (2009) concludes that the upper limit of practically achievable PV capacity is 15% of global electricity supply, generating 6200 TWh.

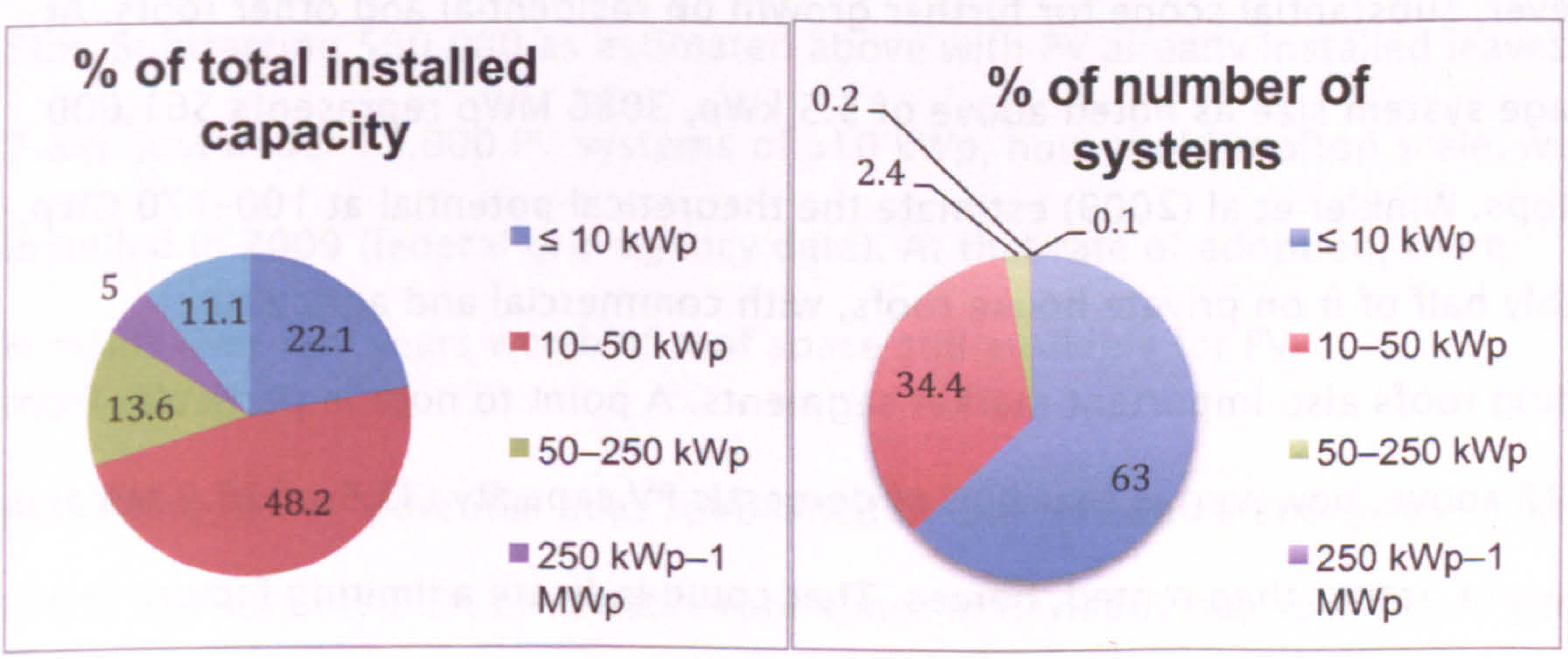
The potential of PV in very large scale systems in desert or other remote regions of the world is analysed in Komoto et al (2009). They foresee annual installation of 2.2 GWp at 2020, 17 GWp at 2030, and 236 GWp at 2050 ; and total installed capacity by 2030 of 100 GWp, and by 2050 of 2000 GWp. Thereafter they expect a massive increase from 2050-2100, reaching a total global capacity of 67,000 GWp of which 20,000 GWp in developed and 47,000 GWp in developing regions.

6.4.4 Market segmentation in Germany

6.4.4.1 Present position

Returning to Germany, market segmentation is relevant to consideration of the outlook for PV growth. In 2005 and 2006, the German PV market was "dominated by small .... systems installed on residential buildings" (EuPD Research, 2008), which comprised over two thirds of sales. Bank financing for smaller systems is quite readily obtainable, and apparently unaffected by the "credit crunch" of the past 2-3 years (Pohl, 2009). As at 2008, small to medium sized rooftop installations made up more than 80% of the market (Lacey, 2009). SolarServer (2010) noted a similar pattern in the first quarter of 2010 : 91% of newly installed systems, making up 51% of new capacity, were under 50 kWp with an average size of 23.2 kWp. Stryi-Hipp (2009) gave figures of 55% of PV on residential roofs in systems of 1-10 kWp, and 35% of 10-100 kWp size on larger houses, public, commercial and farm buildings; but is unclear whether he meant new capacity, cumulative capacity, or number of systems.

The differing size classifications used in those reports make it difficult to know exactly what proportion of PV in Germany is on individual house roofs. Data are, fortunately, available on percentage shares of both total installed capacity and total number of installed systems, as at late 2009, and are presented in Figures 25 and 26 below. The total cumulative capacity installed at that point was 8364 MWp. The 22.1% share of small systems (up to 10 kWp) accordingly represented installed capacity of 1845 MWp, with average system size 5.5 kWp. The data do not clarify whether some of these systems may be on non-residential roofs, for instance small farm outbuildings and registered as separate. It seems reasonable to assume, however, that they are predominantly on house roofs. Moreover, there are some larger systems on residential roofs: see below.



Figures 25 and 26 : proportion of cumulative PV capacity (25, left hand), and of total number of systems (26, right hand) installed in Germany as at November 2009, by system size category. (Source: federal grid agency)

Figure 27 below shows data from the same source on segmentation of the market in terms of the types of building on which PV systems are installed. The higher proportion, 36.9%, on residential roofs is because that category includes larger houses occupied by more than one family, e.g. apartment blocks, whose roofs are able to accommodate larger systems in the 10-50 kWp segment. According to Stryi-Hipp (2007), 20m of the 37m homes in Germany are in apartment buildings. Information about the average roof space per household would be interesting.

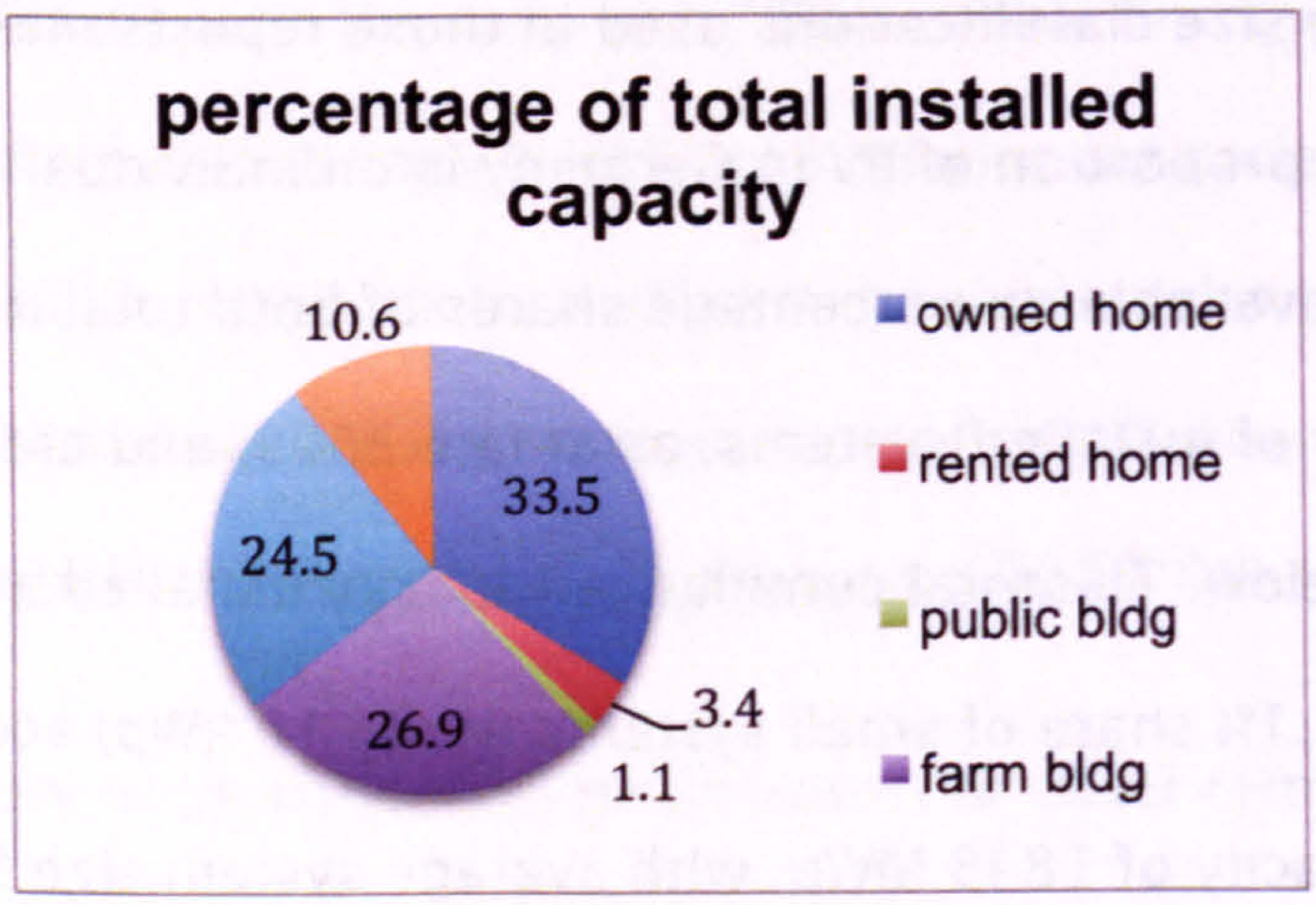


Figure 27 : proportion of PV capacity installed in Germany as at November 2009, by type of building on which installed. (Source: federal grid agency.)

36.9% of the 8364 MWp total capacity in Germany means 3086 MWp on the roofs of private homes. That is already a remarkable performance. There remains, however, substantial scope for further growth on residential and other roofs. At average system size as noted above of 5.5 kWp, 3086 MWp represents 561,000 rooftops. Winkler et al (2009) estimate the theoretical potential at 100-170 GWp, roughly half of it on private house roofs, with commercial and agricultural building roofs also important market segments. A point to note in particular from Fig. 27 above, however, is that 90% of domestic PV capacity (33.5 of 36.9 MWp) is on owned, rather than rented, homes. That could indicate a limiting factor, perhaps difficulty in obtaining landlord's consent for installation of PV or doubts about who would benefit; or that growth in the rented sector is to be expected, as tenants work through such obstacles.

Table 36 below sets out the most recent data on housing in Germany available from Eurostat (http://appsso.eurostat.ec.europa.eu). Eurostat only gives figures as at 2005 for the proportion of all dwellings in Germany owned, 53.3%, and rented, 46.7% ; it does not distinguish between owned and rented houses or apartments.

	2005	2006	2007	2008	2009
apartments, in small block	29.7%	36.7%	35.3%	36.5%	36.3%
apartments, in larger block	18.2%	18.8%	17.9%	17.9%	16.8%
apartments total	**47.9%**	**55.5%**	**53.3%**	**54.4%**	**53.1%**
semi detached houses	17.6%	14.6%	16.2%	15.4%	16.0%
detached houses	31.2%	27.9%	29.1%	28.5%	29.2%
houses total	**48.8%**	**42.4%**	**45.4%**	**43.9%**	**45.2%**

Table 36 : proportion of dwellings in Germany of the main types, 2005–2009 ; shortfall from 100% represents "other" dwelling types (source: Eurostat)

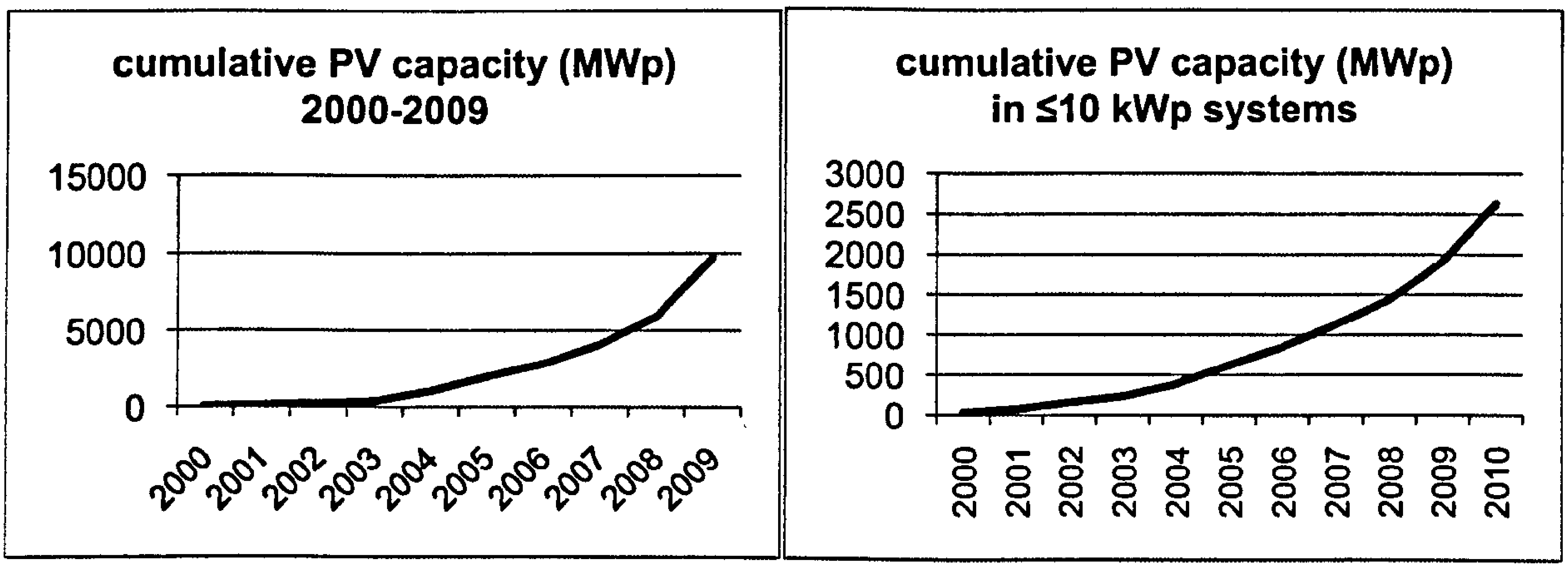
Since Table 36 shows that the proportion of houses diminished from 2005-2009, and expecting that apartments are more likely to be rented, it may be appropriate to assume a 50:50 split as at 2009 between owned and rented dwellings. Nonetheless, even making the conservative assumption that only 50% of houses are owned, and only 50% of them have roofs suitable for PV, that means 8.36 m houses: 37m dwellings as in Stryi-Hipp (2007) x 45.2% houses (Eurostat data) x 50%. Subtracting 560,000 as estimated above with PV already installed leaves 7.8m. Just under 75,000 PV systems of ≤10 kWp, household rooftop scale, were installed in 2009 (federal grid agency data). At that rate of adoption, there remains over 100 years worth of roof space still available for PV.

According to the "potential atlas" published by the renewable energy association (AfEE, 2010b) only 2.5% of suitable roof space in Germany has so far been put to use for PV or solar thermal energy. The renewable energy agency gives the same figure, and total usable roof area as 234.4 square kilometres (AfEE, 2010a).

Grubb (1997) estimated the technical PV resource in Germany in terms of roof area at 532 sq.km. on houses, 214 sq.km. on offices and 242 sq.km. on industrial buildings ; he put their total generating capacity at 121.6 GWp. Simple division gives house rooftop potential as 53.8% of the total area, so 65.4 GWp of capacity. The 3.1 GWp installed as at late 2009 represents just 4.7% of that potential.

These are of course somewhat crude calculations, and it is not clear how Grubb (op cit) treats farm buildings if at all. Nonetheless, 4.7% is in line with the view of Seeliger (2009) that there is still scope in Germany for a twentyfold increase in PV capacity on rooftops; and would put take-up of PV interestingly into the "early adopters" category of the innovation diffusion theory of Rogers (2003). Even if such estimates are erroneous by 50%, they still indicate considerable room for continuing growth of PV capacity.

Figures 28(a)&(b) overleaf both bear a resemblance to the early section of an innovation diffusion S-curve, and to the logistic curve that solar promotion association SFV advocates PV growth in Germany should follow (Figure 23 in 6.2.8 above). That may, of course, be coincidence; and a weakness is that the 2007 and 2008 data points in Fig. 28(b) are interpolated, assuming a steady fall in small systems' share of total new capacity, as exact data could not be found. The annual growth in 2010, estimated at 7400 MWp, continues the trend. If planned measures limit annual growth henceforth to 3000-3500 MWp, the curve will will reduce somewhat in gradient, but not level off: it leaves a good deal of scope for further growth before peaking.



Figures 28(a)&(b): (a) growth of cumulative installed PV capacity in Germany 1999-2009 (source: BMU 2010b) ; (b) growth of cumulative capacity in small, ≤10kWp, rooftop systems1999-2009 (sources: solar industry association BSW and federal grid agency)

6.4.4.2 Outlook

EPIA (2010a) predict a shift in the PV capacity going into various market segments. The cessation of feed-in tariff support for ground based arrays on arable land will adversely affect that segment. Measures increasing feed-in tariff rates for in-house consumption of PV electricity, making that more attractive relative to export to the Grid, could boost installations on residential and commercial building rooftops. The industry association has observed (BSW, 2009) home owners and farmers being keen to invest.

On the other hand, the head of solar promotion association SFV points to the sharp reduction in the proportion of new installations of small PV systems (≤5kWp) going onto individual house roofs (von Fabeck, 2010b), which in 2009 made up only 4% of installed capacity. The picture is less stark when one considers systems up to 10 kWp, suitable for larger houses as well as small terraced ones. Data published by the Federal Grid Agency show that such systems comprised 12.4% of new capacity installed in 2009, and 46.9% of the number of individual systems (of whatever size).

Since the beginning of 2009 it has been a legal requirement in Germany to register a newly installed PV system with the Grid agency. A complete listing of systems installed each month, showing location as well as size, is available on the agency's website (www.bundesnetzagentur.de). The results of initial analysis of these data are in Figures 29 below, 30 and 31 overleaf. Figure 29 shows the overview for the year, Figure 30 the month by month and system size breakdown of new PV installations in 2009 in terms of capacity; and Figure 31 the breakdown in terms of number of individual systems installed.

(Caveat. The choice of system size category boundaries inevitably affects the number of systems counted within each category. For example, one of 10.01kWp is treated as in the " >10kWp" category, even though only 100Wp larger. The number of such borderline systems is, however, not considered large enough to distort the wider picture significantly. It will also be apparent that the size categories are not equal in breadth. However, the scale shows the number of systems in each category.)

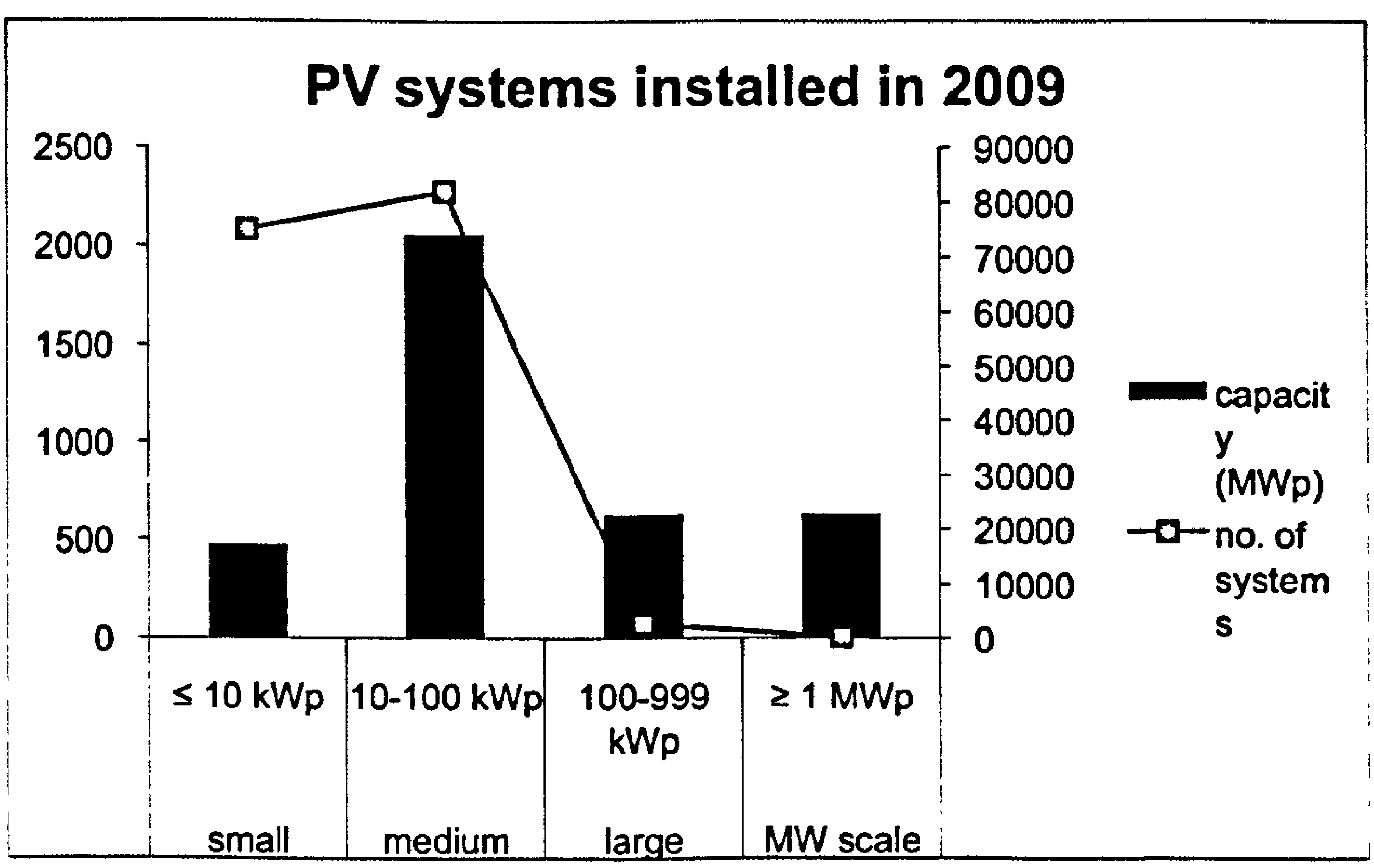


Figure 29 : overview of new installations of PV systems in 2009 by size range – capacity and number of systems (Source: federal grid agency)

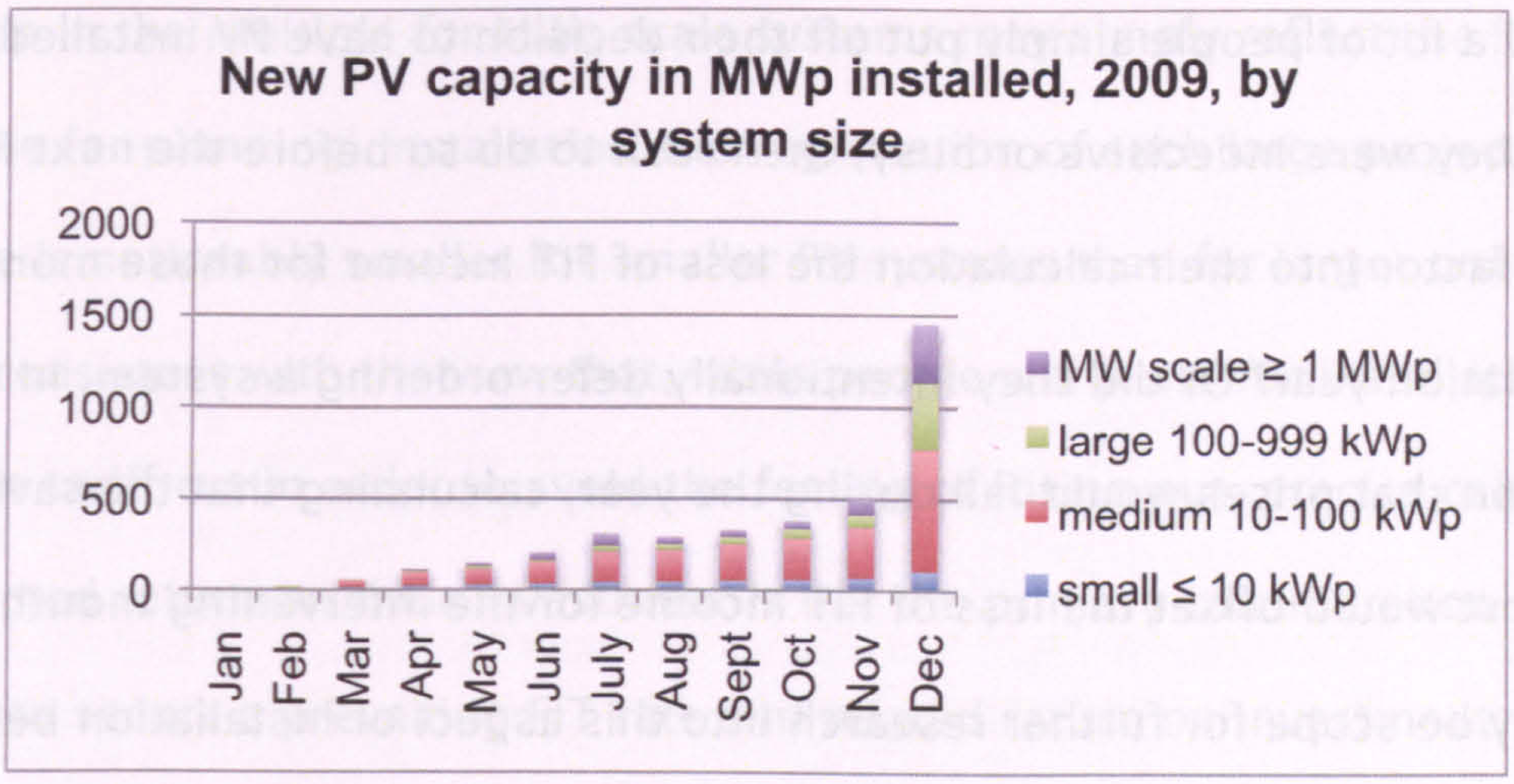


Figure 30 : volume of PV capacity (in MWp) newly installed in Germany in 2009, by system size range. (Source: federal grid agency)

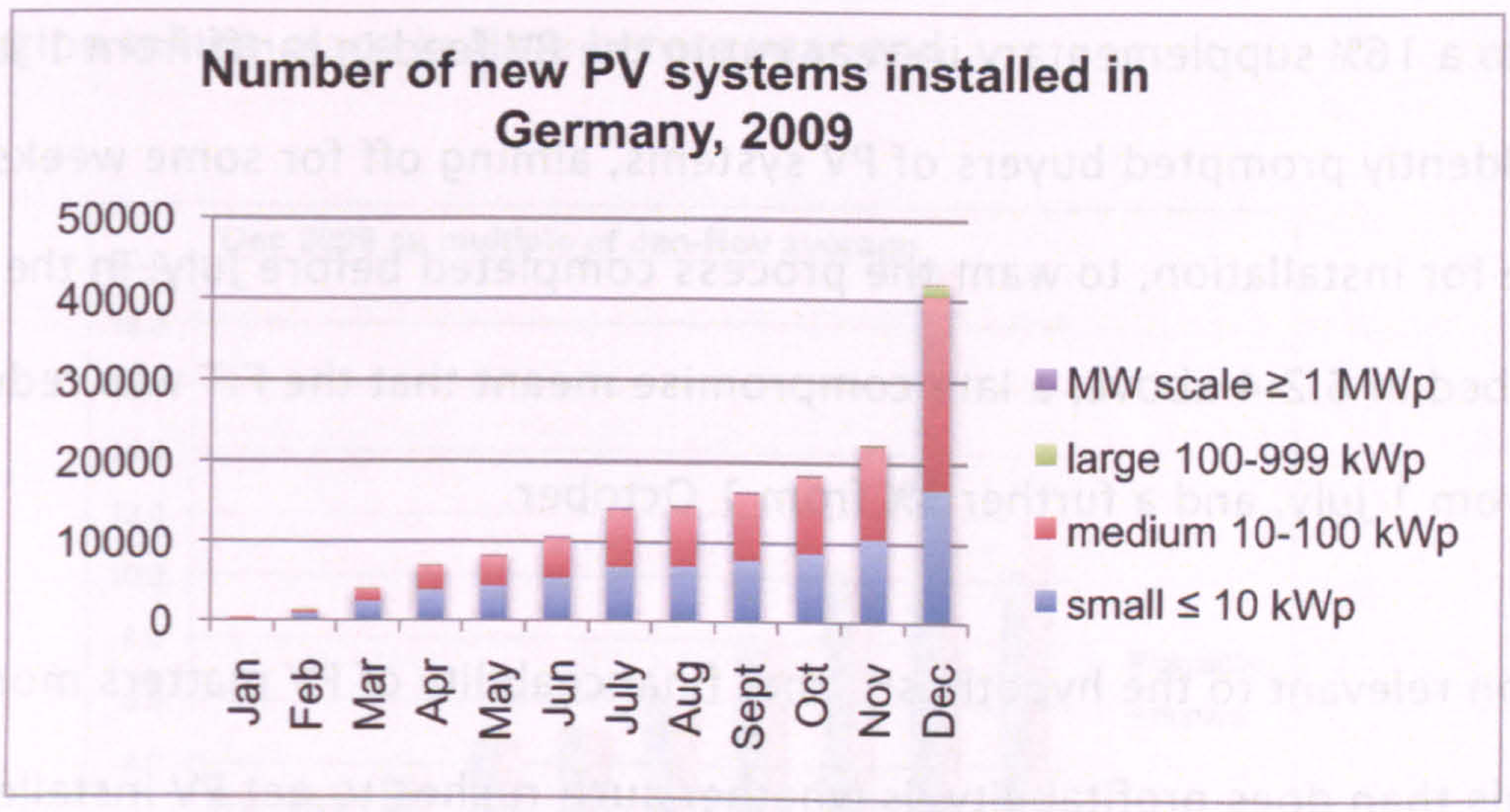


Figure 31 : number of PV systems newly installed in Germany in 2009, by system size range. (Source: federal grid agency)

Two points of particular note are the importance of medium sized PV systems in the 10-100 kWp range, and the surge in installations at the end of year.

6.4.4.3 Year-end surge in installations

As is clearly visible in Figures 30 and 31 above, both the number of systems and the total capacity installed in 2009 rose markedly in November and especially December. The ostensible reason is a rush to "beat the cut" in anticipation of a reduction in the feed-in tariff from the following 1 January. That may appear a little odd, since the German system makes the FiT payable for the remaining months of the year of installation in addition to the subsequent 20 calendar years. Did a lot of people simply put off their decision to have PV installed, because they were indecisive or busy, then rush to do so before the next FiT cut - failing to factor into their calculation the loss of FiT income for those months of the installation year? Or did they intentionally defer ordering a system, in the expectation that prices would fall during the year, calculating that the saving on system cost would offset the loss of FiT income for the intervening months? There may be scope for further research into this aspect of installation behaviour. The similar surge of installations apparent in the federal grid agency data for June 2010 was arguably more logical. Political discussions had for months pointed to a 16% supplementary in-year cut in the PV feed-in tariff from 1 July, which evidently prompted buyers of PV systems, aiming off for some weeks of lead time for installation, to want the process completed before July. In the event, as described in 6.2.4 above, a late compromise meant that the FiT was reduced by 13% from 1 July, and a further 3% from 1 October.

A question relevant to the hypothesis, that financeability of PV matters more to individuals than does profitability, is whether such rushes to get PV installed before FiT cuts imply that buyers' primary concern is the expected return on investment. It is arguable that even persons to whom the precise level of return is not a deciding factor will still want to avert a perceived "loss", because it is human nature to be unhappy if we feel we have missed out on something - as when we complete a purchase that we would have made anyway, but feel a loss because we did not bring our loyalty card and so did not gain a few points.

A more substantial response, however, is that the surge in year-end installations is more apparent for larger PV systems. Figure 32 overleaf shows what multiple were the December 2009 figures for new PV installation, in terms of capacity and of number of systems installed, of the average figure for January-November 2009.

The drop in the multiple for MWp scale systems may simply reflect the longer lead time for planning, installation and registration of such large projects. The multiple is noticeably smaller for smaller PV systems than for larger ones. That seems consistent with the view that, while people will press for installation before a feed-in tariff cut in order to avoid the feeling of losing out, precise calculation of expected return on their investment is not the primary consideration. If they wanted to secure a prevailing FiT rate and related return on investment, one would expect them to press for installation earlier in the year, thus gaining extra months of FiT payment and avoiding the risk that winter conditions could prevent installation taking place in time before year end.

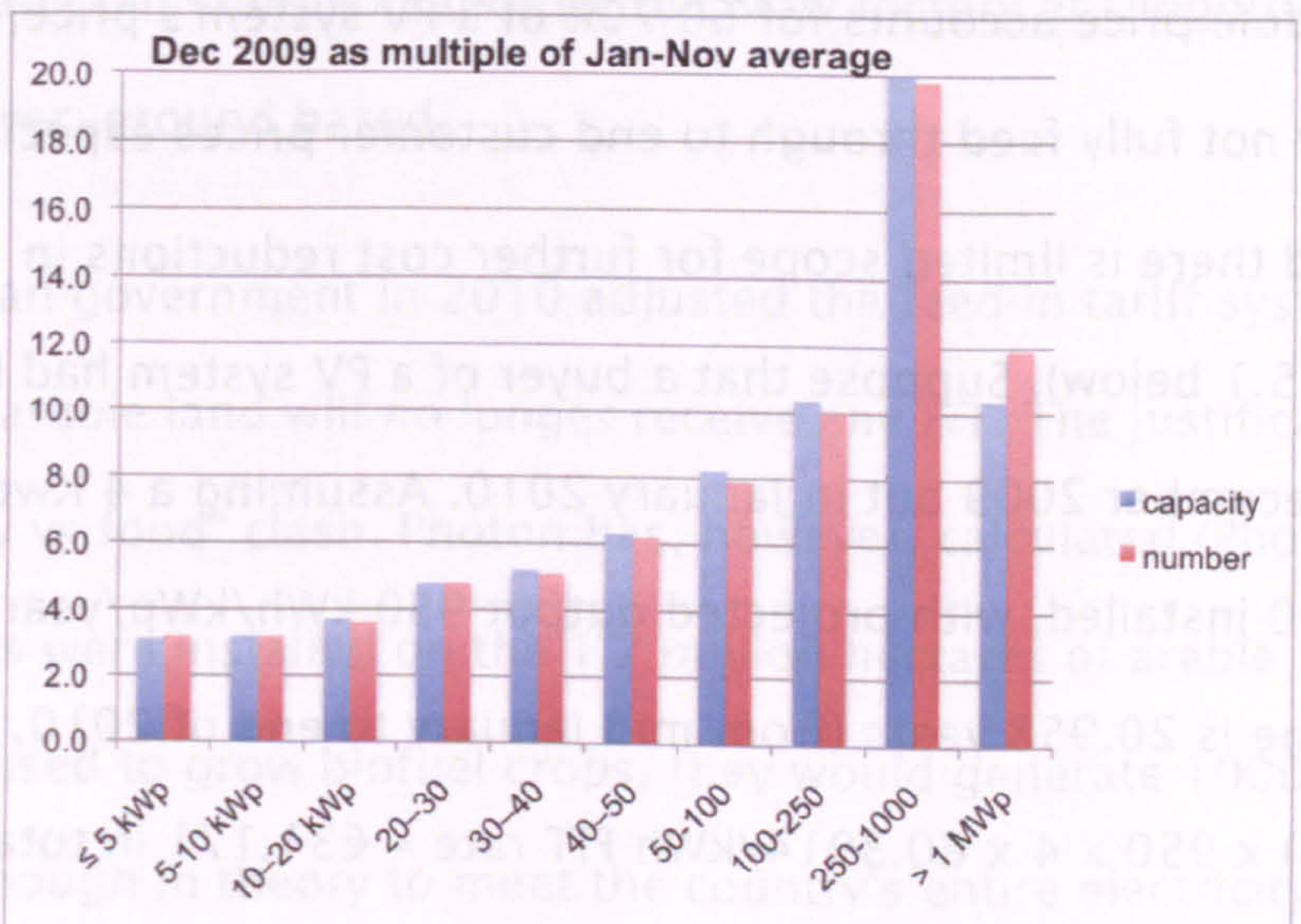


Figure 32 : PV capacity, and number of systems, installed in December 2009 as multiple of the respective averages for January-November 2009. (Source: federal grid agency)

It is not clear – and offers scope for further research – to what extent individual households considering installation of PV take account of all timing factors relating to cost and benefit. There is an interplay between the feed-in tariff rate prevailing at the time of installation, the length of the FiT payments period, and the current cost of a PV system. Buyers may expect system cost to fall in line with the degression in the FiT rate, or in 2010 *vice versa*, as has by and large been the experience since the introduction of the FiT mechanism in 2000.

Can buyers, however, count on a steady reduction in prices during the year, enabling them to time their installation for maximum benefit? Recent monitoring indicates that spot market prices for PV modules display a declining trend, but with fluctuations from month to month (Photovoltaik, 2010d). Crystalline silicon modules made in Germany fell in price from €3.00 per Wp at the beginning of 2009 to €2.10/Wp at year end: a fall of 30%, or 2.5% per month on average. There were sharp fluctuations in May 2009, first a price rise from €2.60 to €2.80, and then a drop to €2.40 (all per Wp). For the rest of the year prices varied by only some €0.10 up or down - which could easily, however, be enough to offset an expected 2.5% drop and throw out buyers' calculations.

Moreover, the module price accounts for 60-70% of a PV system's price, spot market prices may not fully feed through to end customer prices especially of small systems, and there is limited scope for further cost reductions in installation (see 6.5.1 below). Suppose that a buyer of a PV system had it installed, not in December 2009 but in January 2010. Assuming a 4 Kwp system which cost €12,000 installed, with projected output 950 kWh/kWp/year, then feed-in tariff income is 20.958 years (from mid January to end of 2010, plus the 20 following years) x 950 x 4 x €0.3914/kWh FiT rate = €31,171 in total. The corresponding calculation for the same array installed in December 2009 gives total FiT income of €32,756. The difference is €1585, which translates into around 0.5% higher return on investment. This means that the earlier installation more than offsets the extra months of income at lower FiT rate. Any fall in system price between December 2009 and January 2010 would, however, reduce that difference; and one would expect dealers to factor that into prices.

6.4.4.4 Location of PV systems

The grid agency data do not specify on what type of building each individual PV system is installed. On the basis of anecdotal examples reported in the press and observed while travelling in Germany, it is assumed in the present analysis that the four system size ranges correspond in general to types of location as set out in Table 37 below.

up to 10 kWp	roof of individual house
10.01–100 kWp	roof of apartment block, community building (e.g. school, town hall), commercial building, farm building
100.01–999.9 kWp	roof of industrial or major commercial building (e.g. factory, distribution warehouse)
1 MWp and above	ground based array, unusually large roof space

Table 37: expected typical locations of PV systems of different size ranges

There are a few examples of MWp scale PV arrays on roofs, one being that of the Munich trade fair complex, another the BMW factory at Dingolfing in Bayern. Most are, however, ground based.

The German government in 2010 adjusted the feed-in tariff system such that PV arrays on arable land will no longer receive any FiT. The justification was to avoid an "energy vs food" clash. Photon has, however, calculated (Photon, 2010b) that if PV systems were installed on the 1.7 million hectares of arable land in Germany currently used to grow biofuel crops, they would generate 1000 TWh of electricity a year - enough in theory to meet the country's entire electricity, heating and mobility needs, leaving aside issues of storage of course. The Renewable Energy Agency's atlas of renewable energy potential in Germany (AfEE, 2010b) shows 1700 hectares occupied by ground based PV arrays. The Agency predicted 10,000 ha by 2020. The government's removal of feed-in tariff support for PV on arable land must call into question the achievability of that level of capacity.

Ground based PV systems on "brownfield" sites, such as former military bases or landfills, will continue to qualify for FiT payments. The rate was reduced in 2010 by 11%, as compared with 16% for rooftop systems. The largest example is the 53MWp array on a former army training ground at Lieberose in Brandenburg.

MW scale projects are often financed by a solar investment fund, and accordingly tend to attract people who are seeking an attractive return, and for whom a share in a large PV array is not materially different from one in for instance a forest or a unit trust. They differ from collective investment in a community system, where participating residents can actually see "their" part of the array on e.g. a public building.

It is of course a characteristic of PV that it can be installed on a wide range of roofs and other surfaces which are not otherwise put to use. Further evidence of how Germany has embraced PV can be found in the range of ideas for its deployment. It would be possible to present a hundred examples here; but to save space it is hoped that three will give a sufficient flavour.

⇒ The Rewe supermarket group has announced (Rewe, 2009) plans to increase PV capacity on its warehouse roofs from 3.5 MWp to 8 MWp.

⇒ A developer in southwest Germany started out with a concept, as described in RenewableEnergyAccess (2007), to install a PV power plant; then had the idea of putting industrial units under the PV modules, the feed-in tariff income enabling him to offer lower rents for the units and attract tenants.

⇒ In the north of Hessen, the Amazon company car park is equipped with 73 two axis tracker PV systems, each with 8.28 kWp capacity, and total annual output of 750 MWh (Reeh, 2010).

6.4.4.5 Regional distribution

Federal grid agency data show that in 2009 just under 160,000 new PV systems were installed in Germany. According to the Bayern industry ministry 60,000 of those went into that Land, with total capacity of 3.5 GWp (reported in PNP, 2010), and the outlook for 2010 was for the number to increase. From these figures, the average system size in Bayern in 2009 was 58.3 kWp. That suggests that many installations were on commercial, public, and farm building roofs.

6.4.4.6 Farm buildings

EuPD Research, BSW and Solarpraxis carried out in 2009 a new study entitled "Photovoltaik in der Landwirtschaft - Renaissance eines Marktsegments in Deutschland?" ("PV in agriculture - renaissance of a market segment in Germany?"), described in Neidlein (2009a). There are in Germany 374,500 farms of 2 hectares or more. Almost one third of those are in Bayern. Next in number of farms come Baden-Württemberg (B-W), Niedersachsen and Nordrhein-Westfalen (NRW). EuPD Research assess the farm building roof space potentially usable for PV, in terms of the capacity it would hold, as:

> Bayern 6.26 GWp, Niedersachsen 4.55 GWp, B-W 2.67 GWp, NRW 2.48 GWp, Schleswig-Holstein 1.54 GWp, etc* ; Germany total = 22.27 GWp.
> (* map on p.64, op. cit., gives figure for each Land)

So far only 8.5% of that potential capacity Germany-wide has been installed. The proportion is especially low in Niedersachsen, Schleswig-Holstein and the eastern Länder. It is much higher in parts of Bayern and Baden-Württemberg ; e.g. Schwäbisch Hall 40%.

Financing is not a problem, as farmers have good credit rating helped by owned buildings as collateral, and access to regional Sparkasse and specialised finance institutions. There are 258 "Maschinenring" equipment buying cooperatives in Germany, to which 54.7% of all farmers belong. They play an important role in distribution of PV, including by forming subsidiaries for that specific purpose. Over 90% of farmers surveyed felt well informed about PV; over 80% were positive about it ; 67% interested in getting PV ; and 14% had concrete plans to have PV installed in the near future. The minimum return on investment that the farmers surveyed wanted was 6%, and one third of them wanted at least 8%. But service, including after sales, is also an important consideration.

In the period 2005-2008, average annual new PV capacity installed on farm buildings was 200-250 MWp. EuPD Research's forecast for 2009 was 285 MWp, and for 2010 was 314 MWp. Typical system size is in the range 20-100 kWp. The study found some signs that the most attractive roofs (in terms of orientation and lack of shading) were being filled up, such that this market segment might be saturating. On the other hand, falling PV system cost should mean that further roof space would become attractive, creating room for growth.

6.4.5 Conclusions

A comprehensive analysis of world PV markets is beyond the scope, and space constraints, of the present thesis. It is hoped that the foregoing brief survey nevertheless allows fairly optimistic conclusions to be drawn, namely that:

- PV is now solidly rooted worldwide as a clean energy source ;
- it is no longer a niche technology, but with the support in particular of feed-in tariff incentive mechanisms has broken through into the grid connected electricity supply market, and become mainstream ;
- a succession of countries are boarding the PV train, opening up new markets and scope for the industry to increase further in scale ;
- there is still very large potential to exploit, even in existing major markets like Germany.

Industry commentators properly counsel against over-optimism, warning for instance that "The PV industry continues to have a fragile demand/supply picture and the necessity to develop new markets remains crucial. .... None of these new markets will boom overnight...." (Mints, 2010a). Notwithstanding, it is difficult to see how PV could now have a future other than of assured continuing growth. As the same analyst has shown (Mints, 2010b), to date the PV industry has never experienced a decrease in annual demand.

The issue is, rather, how rapidly and over what timescale that growth will occur. The relevance of these conclusions to this thesis is that they apply equally to demand for PV in Germany. Demand across a growing range of markets will enable the industry to continue its journey down the experience curve, and to continue the reduction in the cost of PV, spurred on further by competition from Chinese manufacturers. See section 6.5 below on developments in the industry and PV technology, and what they may mean for cost.

With the exception of a few trial installations, all PV systems are built from standard modules, so it is in effect a global market. Accordingly, growing demand wherever it arises will enable the industry further to increase production scale to satisfy it, thereby bringing down cost. As Michel (2007) has pointed out, when would-be buyers can point to solar panels offered on the Internet at lower prices, local distributors will be compelled to reduce their prices correspondingly. The benefits of that cost reduction will apply in Germany as elsewhere, and not only in maintaining the affordability and financeability of PV systems as feed-in tariff support reduces.

It also means that, given the relatively high price of electricity to retail customers in Germany, the cost of PV electricity will in the near future reach "Grid parity". That is the point at which the imputed cost per kWh of PV electricity - factoring in system price, financing costs, insurance, maintenance etc - crosses the rising price of grid retail electricity. Examples from a German price comparison website, www.epreise24.de, in late December 2010 indicate a retail price of €¢20-24 per kWh (based on 4000 kWh annual consumption by a household in Munich). We may take the feed-in tariff rate as a close proxy for the cost of PV electricity, albeit it is intended to include some return on investment and will accordingly overstate the cost slightly. The FiT rate for small rooftop systems up to 30 kWp as from 1 January 2011 will be €¢28.74 per kWh (Bundesnetzagentur, 2010b), with the possibility of a further in-year cut in the rate as occurred in 2010. The rate has fallen by 33.2% since the end of 2009. A further reduction of 23% would bring the FiT rate to €¢22, very much in line with grid retail prices. The implications for PV support mechanisms and demand for PV systems will be discussed in 6.7 below. Suffice it to say here that the effect on demand for PV is very likely to be positive.

6.5 : Impact of PV industry and technology developments on cost

"When demand for oil and coal increases, their price goes up. When demand for solar cells increases, the price often comes down."

(Gore, 2008)

6.5.1 Introduction

The PV industry continues to grow and evolve ; new developments are reported frequently, even weekly. A comprehensive review of the state of and prospects for the industry would require disproportionate space. This section accordingly offers a necessarily brief overview of developments.

There are two principal strands to developments in the last few years:

- continuing advances in production processes and PV technology ;
- the expansion of manufacturing scale, including the rise of China.

Both have a direct impact on the cost of PV systems, which in turn has an effect on market demand, particularly in the commercial and professional investor segments where expectations of return on investment tend to be higher.

Manufacturers of PV cells and modules have long striven to reduce costs through process and technology improvements, in order to keep pace with the annual degression of feed-in tariffs, and to maintain their profit margins to provide shareholder return and to fund investment in capacity and R&D. The results are seen in the "experience curve", also referred to as "learning rate", that the industry has maintained for decades of around 20% reduction in cost for each doubling of cumulative production volume: see e.g. Poponi (2003), van der Zwaan & Rabl (2004). Schaeffer & de Moor (2004) concluded that PV cost reduction was "right on track" to become a large scale source of electricity, though vision and support would continue to be needed. Albrecht (2007) analysed the risk reducing benefits of PV in an energy supply portfolio, in which terms it is "an attractive technology".

Efforts to achieve further cost reductions continue, in such areas as lower requirement for solar grade silicon through reducing wafer thickness and sawing waste; better cell surface and layer structures, moving electricial contacts to the back side to eliminate shading, anti-reflective coatings and edges to improve cell output; and "balance of system" elements which make up over half the cost of an installed PV system. For descriptions of such developments see for example Fujisaka (2010), Kho (2009), Sullivan (2010), Laird (2010), and large sections of the Proceedings of the annual European Photovoltaic Solar Energy Conference, held latterly in Valencia in 2008 and 2010, and Hamburg in 2009, for example Hoffmann et al (2009).

Stryi-Hipp (2008), then head of the German solar industry association, explained that PV modules make up 60-70% of the cost of a PV system. Installers have already cut their margins as far as they can. Module producers operate with narrow margins, so their scope to reduce prices is limited. Accordingly, price reductions to keep pace with falling feed-in tariff rates need to come primarily from manufacturers of solar silicon, wafers and cells.

The European industry's joint initiative with the EU PV Technology Platform (EPIA & PVTP, 2010) aims to achieve a series of cost and efficiency targets, as set out in Table 38 below. Those for cost per kWh of PV electricity by 2015 are especially interesting, as they bracket prevailing grid retail prices in Germany: a further indication that 'Grid Parity' is on the horizon (see section 6.7 below).

	2007	2010	2015	2020
PV system installed price, €	5000	2500-3500	2000	1500
PV electricity cost per kWh, in southern Europe, €	0.30–0.60	0.13–0.25	0.10–0.20	0.07–0.14
Crys-Si module efficiency	13–18%	15–20%	16–21%	18–23%
thin film module efficiency	5–11%	6–12%	8–14%	10–16%
inverter lifetime (years)	10	15	20	> 25
PV module lifetime (years)	20–25	20–25	25–30	35–40

Table 38 : European industry targets for PV cost and efficiency ; source EPIA & PVTP (2010), p.7

A key driver of cost reduction of PV systems is scale of manufacturing, as it has been for other electronics products. One of the first digital cameras, the Kodak DCS-100 marketed in 1991, had 1.3 megapixel resolution and cost $13,000 (Wikipedia, 2011). 20 years later, prices have fallen and resolution improved, both considerably. Just four years ago typical PV production lines had capacity of 30-60 MW per year (e.g. Renewable Energy World, 2007); now GW scale production is becoming common (e.g. Hoferichter, 2010).

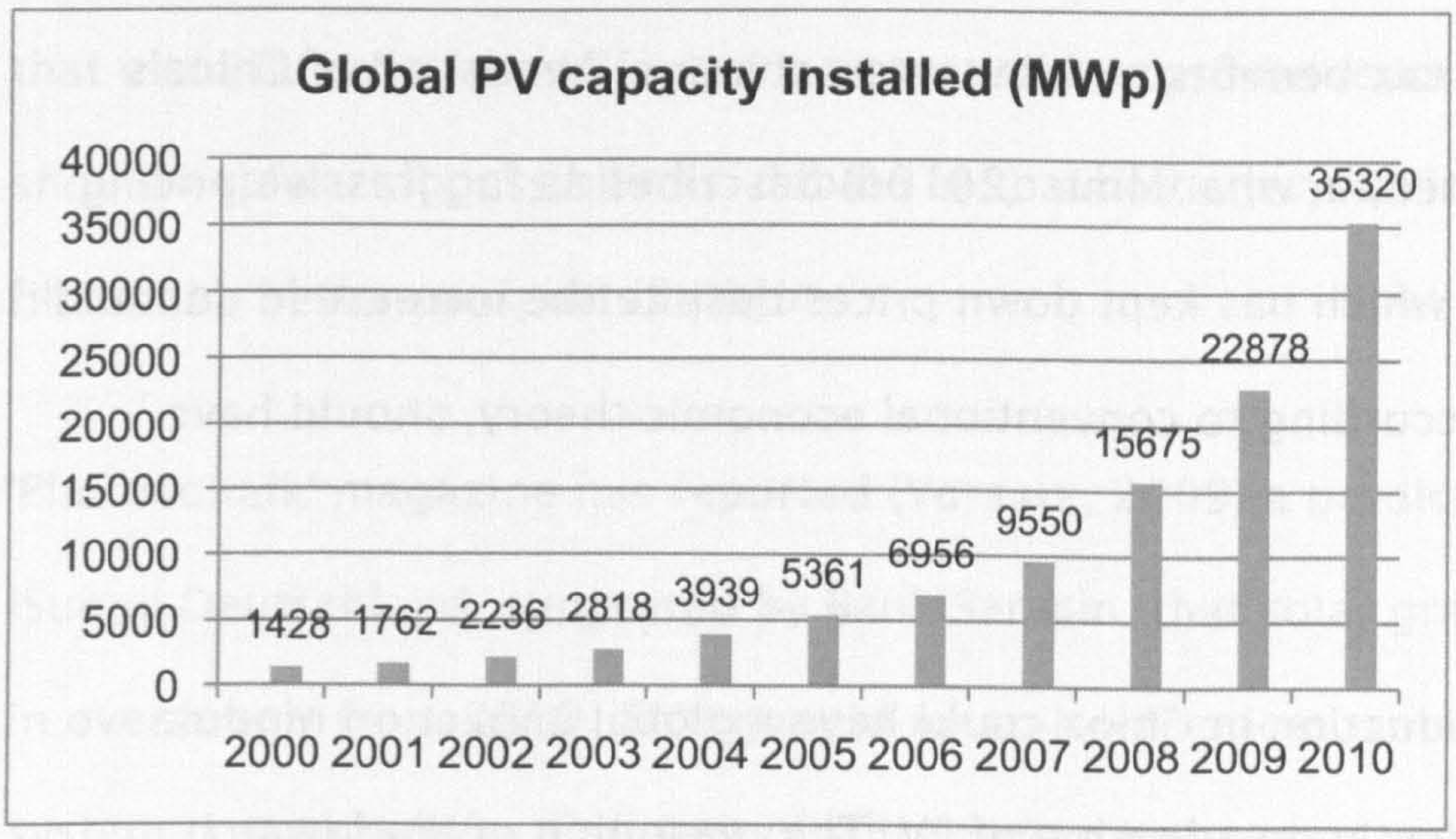


Figure 33 : PV capacity installed worldwide in MWp, 2000-2010 (EPIA)

EPIA & Greenpeace (2011) report global installed PV capacity as having grown 27-fold from 2000 to 2010, as illustrated in Figure 33 above; and that Germany was still by some distance the largest market in 2009, at 53% of new installations, over Italy with 10% and the USA and Japan with 7% each. Forecasts of PV production volumes are broadly in line with those for PV demand described in Section 6.4 above. Jäger-Waldau (2009) charts global PV production capacity as at 2008 and plans for 2009-2015. The increase is almost linear up to 2012, slowing between then and 2015, but nevertheless amounting to around a four-fold growth from about 16 GW to over 60 GW of planned capacity.

Colville (2010) expects 60% growth in each of 2010 and 2011 in investment in cell and thin film panel manufacturing equipment, with a caveat about potential overcapacity in crystalline silicon cell production. GW scale additions to thin film production capacity have been announced in Japan and the USA (NBuzz, 2009; Solarbuzz, 2009a). The major growth is, however, occurring in China. iSuppli

(2010) reported that Chinese producers would expand capacity by 6.4 GW, over 70% of growth by the world top ten companies. China's Suntech Power has taken over the world no.1 slot (Vorsatz, 2010). Daily et al (2011) examine how the Chinese industry accounts for two thirds of global PV production, helped by government grants, tax benefits and low interest loans. Almost all of China's production is exported, in what Mints (2010d) describes as "aggressive pricing for [market] share", which has kept down prices despite the increase in demand from 2009 which, according to conventional economic theory, should have pushed prices up.

Scaling up of PV production in China could have a global impact on module prices, and consequently on adoption of PV. The reasoning of Worldwatch Institute head Flavin, reported in Runyon (2007), is that to achieve success in their domestic market and supply a large part of the PV capacity called for in government plans, Chinese producers will need to drive costs down to the "China price" that the local market will bear. That would in turn either compel producers in other countries to achieve similar price reductions, or enable Chinese suppliers to take a large share of overseas markets too - provided that they can ramp up their manufacturing capacity to the necessary scale. Either way, it means PV becoming increasingly competitive in other markets. There are signs that the "China price" is being achieved, with the lowest bidder for 10 MWp PV electricity supply concessions in China offering around US$0.10 per kWh (Wang, 2010).

A survey by PriceWaterhouseCoopers of the German industry (PWC, 2010b) found a general mood of optimism. The report also warns, however, that competing with Asian (meaning primarily Chinese) producers of PV cells is a difficult challenge; vertically integrated producers of PV modules such as Bosch, Schott and SolarWorld are better placed to compete.

The vision of at least one German PV company executive, the Chief Technology Officer of Q-Cells, is longer term: competitiveness with conventional electricity generation, which means that "the simple truth remains that cost reduction is the ultimate goal for the PV industry" (Holzapfel, 2008). His upbeat assessment is that material costs show "fantastic potential for cost reduction". Manufacturers should explore all possibilities; debate as to whether crystalline silicon or thin film is the better prospect is sterile.

'Photovoltaik' magazine has reported (Vorsatz, 2009) a prediction by consultants iSuppli Deutschland, supported by Bank Sarasin, that solar grade silicon would be in oversupply from 2010. That should mean lower prices, contributing to PV system cost reduction. Collapse of silicon suppliers seems unlikely, as the two major producers - Hemlock and Wacker - are profitable even at selling prices depressed by oversupply. Indeed, Hemlock have announced further expansion of production (Vorsatz, op cit).

Krawinkel (2007) makes an insightful point on PV cost and capacity: that accelerated cuts in the feed-in tariff rate should encourage purchase, hence production, of the most cost-effective PV modules, in terms of efficiency and thus projected output; which would in turn help to build up the installed capacity in MWp, since an array occupying the same given available roof area but of higher efficiency will have a correspondingly higher peak capacity.

6.5.2 PV technology

"Start by doing what's necessary ; then do what's possible ; and suddenly you are doing the impossible"

(Francis of Assisi, 1182-1226)

Various commentators have for years predicted a breakthrough for thin film PV technologies - cadmium telluride (CdTe), copper indium gallium diselenide

(CIGS), and silicon. It may finally be happening. Jäger-Waldau (2009) forecasts that thin film will increase its share of overall PV production capacity from about one eighth in 2008 to almost one third in 2015. According to a survey of the PV industry by German consultants Invensity (2008), thin film is expected to increase its market share to 45% by 2030, when crystalline silicon should have 30%, and "new concepts" the remaining 25%. Nagamatsu et al (2006) suggest that crystalline silicon PV may run out of scope for continuing its learning curve gains, and that thin film may accordingly be a better prospect for growth. Fuhs (2010c), however, describes continuing evolutionary improvements in silicon PV which are taking cell efficiency into the 17-19% range, well in line with industry targets as in Table 38 on p.250 above.

A number of other PV technologies are still under development in laboratories around the world, several of them nanotechnology based. Breakthrough onto the market of any of them would substantially improve the efficiency of solar modules. That would clearly affect the economics, assuming that systems based on the technology concerned would be of comparable cost to present ones. Perhaps more importantly, it would increase the PV electricity output obtainable from the available rooftop space, and thereby the contribution that PV could make to a country's electricity supply - which might in turn be a spur to the development of distributed generation architectures, further facilitating the adoption of rooftop PV. Following are some examples of "third generation" PV candidates.

- QuantaSol Ltd, a spin-off from Imperial College London, announced a quantum well concentrator cell with 28.3% efficiency at >500 suns (Solarbuzz, 2009b).

- Nanometre scale antennas developed at the US Department of Energy Idaho National Laboratory to collect electromagnetic radiation at solar wavelengths, known as "nantennas", may enable a new way to convert sunlight including infrared directly into electricity at high efficiency - but require matching nanoscale rectifiers. The concept is described in Kotter et al (2008).

- A carbon nanotube based "solar funnel" under development at MIT promises a more efficient way to concentrate solar radiation onto smaller arrays of cells: Trafton (2010).

- Work continues on silicon quantum dot PV technology, which could make possible conversion efficiencies of over 60% ; for instance at the University of Texas, see Clippard (2010).

- A new Cambridge University spin-out, 'Eight19', is developing organic semiconductor based PV cells, of lower efficiency than silicon ones but also lower cost and more flexible in deployment: Reuters News (2010).

For a helpful overview of PV technologies, see Bagnall & Boreland (2008).

6.5.3 Conclusion

The relevance of the foregoing to the prospects for the growth of PV capacity in Germany is simply to do with cost. It seems reasonable to expect that all the R&D work taking place, from laboratories to production floors, will enable the PV industry to continue to reduce the cost of PV systems. In that case, they will remain financeable for individuals, or a good investment proposition in other market segments, even at a lower rate of feed-in tariff support. What happens when Grid Parity is reached is a slightly more complicated question, addressed in Section 6.7 below; but in principle PV should continue to be a worthwhile investment for an individual householder, provided that financing still be obtainable.

It may be that German producers will lose market share to Chinese competitors, to the extent that buyers consider lower price more important than a "Made in Germany" label and feed-in tariff levels are not high enough to make the price premium acceptable. It is also possible that Chinese production will be diverted to its domestic market once the "China price" for PV systems is reached; and that at least some German producers will weather the competition and be able to retain market share. That, however, is outside the scope of the present thesis. The relevant point is that PV will continue to fall in price, so that affordability appears unlikely to be a barrier to continued growth of capacity.

6.6 : Grid integration of PV

"People who seem to have had a new idea have often simply stopped having an old idea."

Edwin Land, inventor of Polaroid

6.6.1 Introduction

Another facet of the future prospects for PV in Germany is the issue of integration of its output into the grid. On this issue too, there are claims and counter-claims. The rate of grid upgrading could prove to be an obstacle to high rates of PV penetration in electricity supply. On the other hand, several informed studies conclude that no difficulties should arise.

6.6.2 Grid overload?

PEI (2010c) reports a call by the chairman of the German energy agency DENA for new PV capacity to be capped at 1 GWp per year, on the grounds that the present grid faces "congestion" because of PV generation, and could only cope with total installed capacity of 30 GWp by 2020. Consultancy firm Putz & Partner (2010) of Hamburg assess that unless 3600 km of additional high voltage transmission lines are built, "overloading" of the grid by wind and PV electricity will threaten the maintenance of grid stability. A few days later DENA (2010) presented grid renewal plans including the 3600 km of new lines, although in the context of taking power from wind farms in the north to consumers in the south. That would seem to imply that PV capacity even in the sunnier south will not be sufficient. Concerns have, however, conversely been expressed that in a few years from now PV peak summer output could equal typical seasonal electricity demand of about 40 GW ; see for example Rentzing (2011). That this might be cause for concern rather than to be welcomed, in terms of reduced carbon emissions for one reason, may have to do with a desire to keep nuclear plants operating at constant output.

6.6.3 No real problem?

The German solar industry association BSW (2010d) rebutted the DENA chairman's argument, pointing to a survey by consultants Roland Berger of grid operators in areas with high PV capacity, who anticipate no fundamental problems in grid management even with rapid PV growth. BSW added that PV electricity is used locally, thus in practice somewhat reduces the load on long distance transmission lines. Only in a few rural areas with substantial wind and PV capacity but limited local demand would some grid strengthening be required. The Renewable Energy Association, BEE (2010b) pointed out that DENA's own study of the grid published in late 2010 showed that renewables could contribute to the stability of the grid. Wind, PV and storable biomass energy working together as a "combi power station" would help ensure stable supply, including by making up for grid constrictions.

A study in 2006-07 in southwest Germany found that there was no problem with integration into the local distribution network, measured against the benchmark power quality standard EN50160, for up to 7 kWp of PV on each of 60 apartments (Laukamp et al, 2008). Results of a modelling study described by Cramer (2008) into the role of PV in future energy supply include that there is excellent correlation between PV output and grid load, such that over 50 GWp of PV output could easily be integrated without new grid capacity or storage. Such practical findings are consistent with the prediction of the IEA (2003) that ".... very small systems on roof tops will be widely spread. As most of the energy will be consumer onsite, the problems for utilities to balance grid energy flows are likely to be manageable until very high levels of penetration are seen.". The PV industry has developed new inverters with reactive power control capability, which industry association BSW (2010e) believes can enable a 200% increase in PV electricity feed-in to the grid without any strengthening being needed.

An increase in electricity storage capacity could well contribute to minimising grid management problems, by time-shifting consumption of renewably generated, including PV, electricity. E.On announced in late 2010 plans to expand pumped storage capacity by 300 MW by 2016 (Singer, 2010), to help integrate renewables. A Boston Consulting Group study reported in Eckert (2011b) forecasts a trebling of electricity storage capacity worldwide as the share of renewables increases. Conversely, Swift-Hook (2010) argues that storage is barely relevant to renewables, because they will always be the last supply source to be shut down. That view, however, disregards the role of storage in increasing in-house use of PV electricity.

Storage at a decentralised level would help to increase the proportion of PV electricity used in-house, further aiding in grid management. The Solar Promotion Association SFV (2011) advocates installation of a 1 kWh rechargeable battery in every house. The Fraunhofer Institute for Wind Energy & Energy System Technology and collaborators have been examining a similar concept. Braun et al (2009) present results of minute by minute monitoring of electricity consumption and PV output, combined with use of lithium ion battery storage of PV surpluses, to time-shift them for later use when PV system output falls below demand. The results are encouraging: in-house consumption increases from around 36% without storage to 45% with one battery, and up to 65% with five. The saving from needing to buy in less grid electricity makes storage economic at a battery price of <€350 per kWh, although that is sensitive to the rate of grid retail price increase. Voltwerk announced in autumn 2010 a 5-8 kWh battery and inverter unit, as reported in Photovoltaik (2010e); the price was not stated, but clearly the market is responding to the need for storage of PV electricity.

Another possible approach to electricity storage is a hydrogen and fuel cell combination. It is not proposed here to embark on an assessment of the prospects for a "hydrogen economy". One encouraging recent development may, however, be worth mentioning. Kanan & Nocera (2008) describe a low cost and efficient catalyst for electrolysis of water, self-assembling from abundant materials, and suitable for use in a system to store PV electricity.

More widely, much has been written about "smart grids" as the key to future integration of decentralised generation into electricity supply. For a basic description of the concept see for example Knight (2008), and Wolfe (2008) for a brief assessment of potential benefits. Rhodes (2010) provides a full analysis from the UK Energy Generation and Supply Knowledge Transfer Network. The next few years may see tension between advocates of rebuilding the present large scale centralised supply system, with more long distance transmission lines and "supergrids", and those of a decentralised system based on microgrids, clusters of microgrids, and clusters of clusters in what is sometimes called an "energy Internet" but might more accurately be described as a fractal architecture - in which there would be a place for high voltage grids, not least to bring offshore wind energy into the supply. That, however, is a topic beyond the scope of the present thesis.

6.6.4 Conclusion

The issue of grid integration of PV generated electricity would not seem to be a serious obstacle to the further growth of PV capacity in Germany. Opponents of renewable energy could seek to use it as an argument for restricting its growth. Even in that case, however, it would be subsidiary to the issue of cost of feed-in tariff support for PV (discussed in section 6.3 above), so unlikely to be decisive.

6.7 : Grid Parity - when? what will it mean?

6.7.1 What is "Grid Parity"?

The phrase "grid parity" is used in more than one sense, but most commonly to mean the point at which the imputed price per kWh of electricity generated by a PV system, including installation and financing costs, becomes equal to that of a kWh bought from the grid at 'retail' price, i.e. that applying to domestic customers. There is of course no single, sharp point when that occurs; it may be more helpful to think of a "fuzzy" crossover region.

6.7.2 When will it arrive?

When grid parity is reached will be different for each PV system owner depending on the interplay of PV system cost and output, and the grid retail cost applying in their particular circumstances. Factors include: the price paid for the PV system and its installation; financing terms; whether PV system cost and income are reckoned over the 20 years feed-in tariff lifetime, or include the value of free PV electricity beyond that; the proportion of PV electricity used in-house; the level of solar radiation at the location, hence PV system output and FiT income; which grid tariff applies, among the hundreds on offer; the rate of future increase in the grid retail tariff. As Table 39 and Figure 34 show, the typical household electricity price in Germany increased every year from 2000-2009.

year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
grid retail price €¢ per kWh	13.94	14.32	16.11	17.19	17.96	18.66	19.46	20.67	21.65	23.21
year on year increase	2.73%	12.5%	6.7%	4.48%	3.9%	4.29%	6.22%	4.74%	7.21%	2.73%

Table 39 : representative price of electricity to household users in Germany, 2000–2009 (source: German Energy Industry Association BDEW)

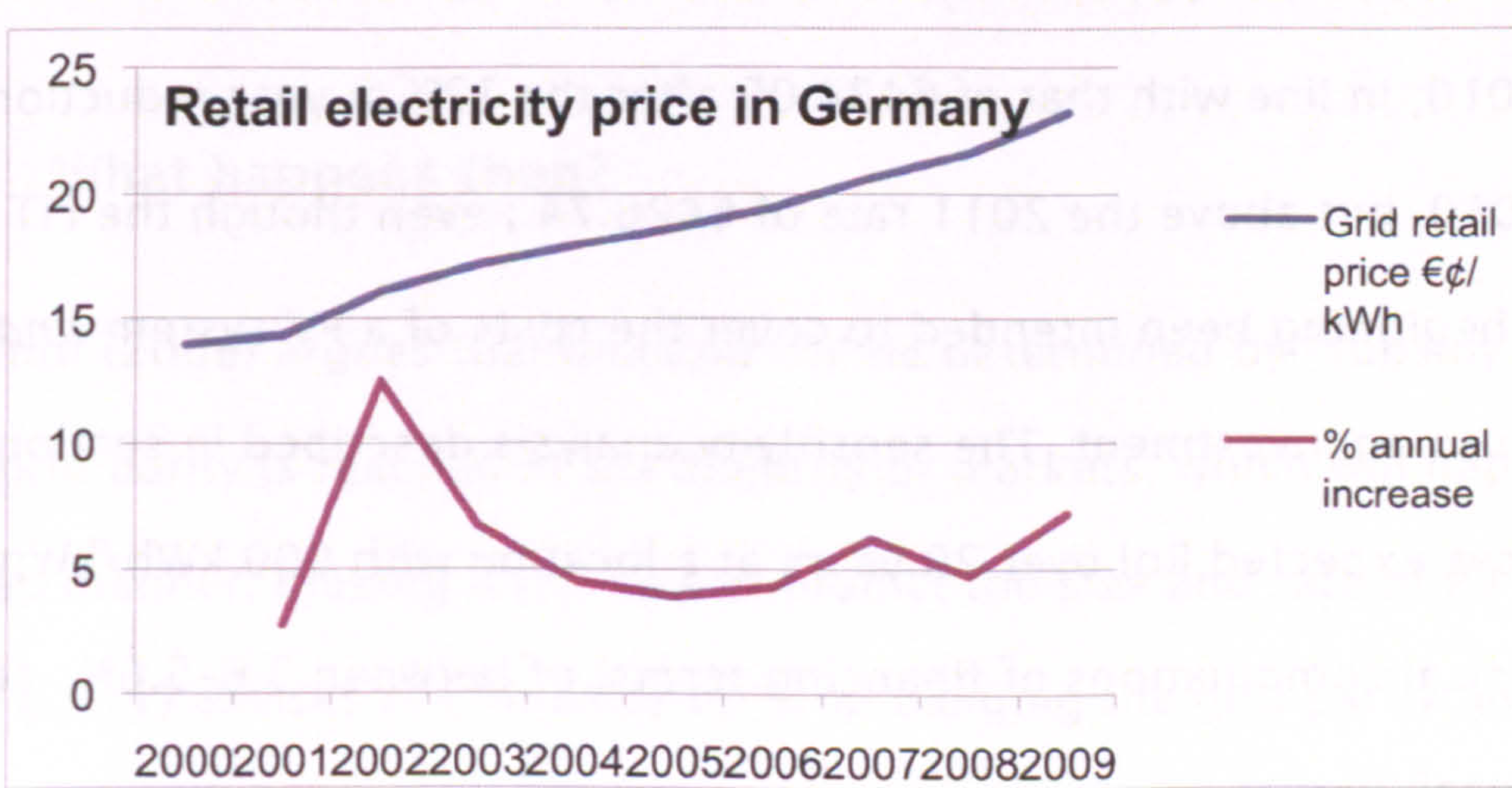


Figure 34 : representative price of electricity to household users in Germany 2000–2009 (source: German energy industry association BDEW)

The prevailing feed-in tariff rate for small PV systems (<30 kWp) is taken as a reasonable proxy for the cost of PV electricity; if anything it slightly overstates the cost, since as discussed in Chapter 5 PV system owners generally receive a small return on the investment. Figure 35 below shows extrapolated FiT rate and grid retail price, indicating that the cost of PV electricity is likely to fall below that of grid retail electricity in 2012-13 for Germany as a whole.

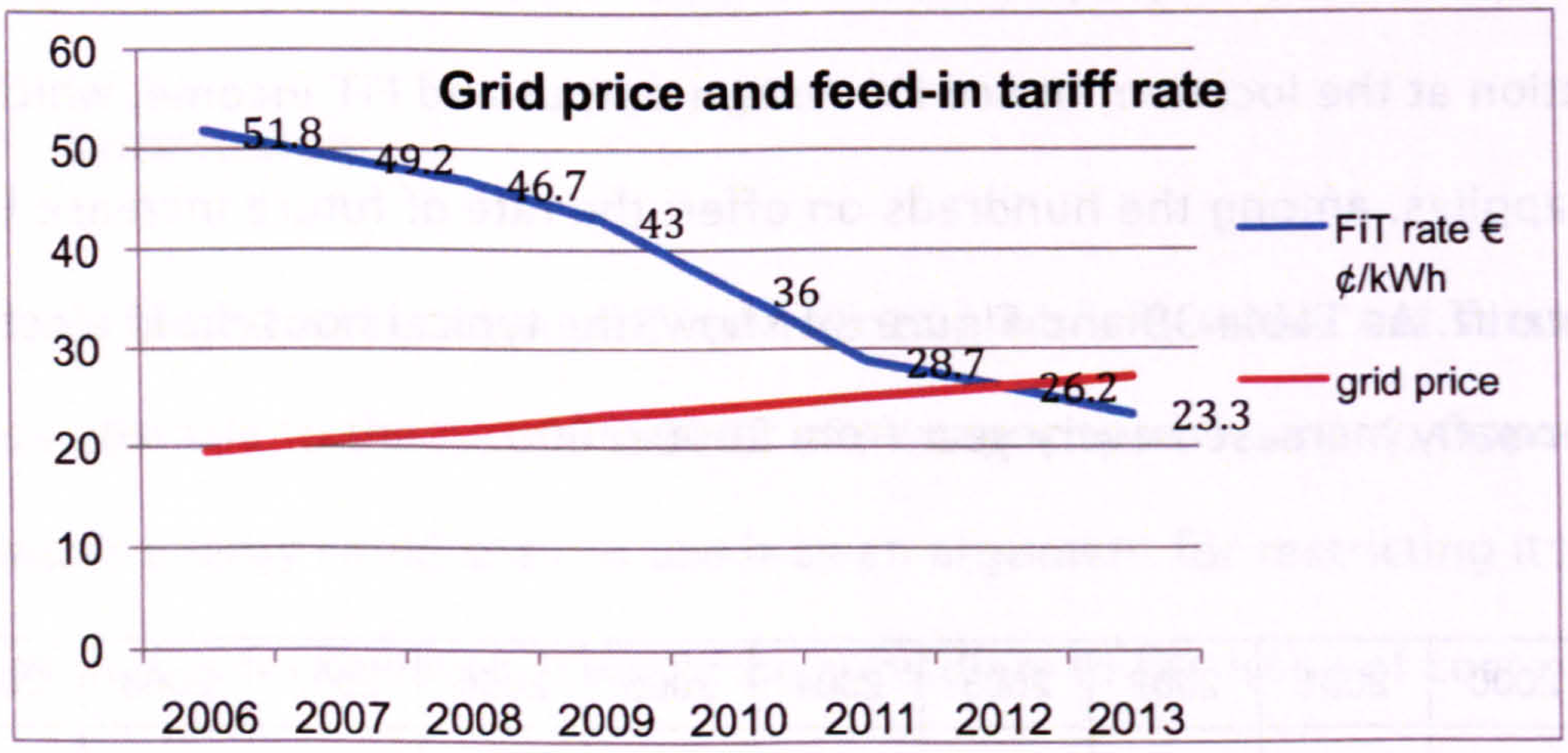


Figure 35 : comparison of feed-in tariff rate (2006-11 actual, 2012 and 2013 assuming 11% annual degression) and grid retail price (2006-09 actual as in Table 41, 2010-13 assuming 4% annual increase)

A Fraunhofer Institute study reported in Kost & Schlegl (2010) arrived at a levelised cost of PV electricity from systems up to 10 kWp of €¢30-34 per kWh, for output of 900 kWh/kWp/year. That is below the FiT rate of €¢39.14 for the first half of 2010, in line with that of €¢34.05 after the 13% in-year reduction from 1 July 2010, but above the 2011 rate of €¢28.74 ; even though the FiT rate has from the beginning been intended to cover the costs of a PV system *and* produce a return on investment. The sensitivity analysis described in section 5.2 earlier produces expected RoI over 20 years at a location with 900 kWh/kWp/year output, for typical combinations of financing terms, of between 3.6-5.6% : see Table 40 overleaf.

Financing terms	Expected RoI
50% of system cost borrowed over 12 yrs at 5% interest	3.62 %
50% borrowed over 12 yrs at 4.5%	3.70 %
50% borrowed over 10 yrs at 5%	3.75 %
50% borrowed over 10 yrs at 4.5%	3.81 %
75% borrowed over 12 yrs at 5%	5.23 %
75% borrowed over 12 yrs at 4.5%	5.40 %
75% borrowed over 10 yrs at 5%	5.51 %
75% borrowed over 10 yrs at 4.5%	5.64 %

Table 40 : expected return on investment in a PV system with output of 900 kWh/ year/kWp, for representative combinations of financing terms (source: sensitivity analysis, section 5.2 of thesis)

There is of course room for debate about precisely how the feed-in tariff rate and the grid retail electricity price will evolve in the coming few years. A number of utilities, including RWE but not E.On, announced price increases of about 7% from the beginning of 2011. On the other hand, customers may be able to obtain lower prices by switching supplier. The degression in the FiT rate might be less than the 11% assumed in Figure 35 ; although it was 13% from January 2011, and as noted in 6.2.8 above there may be a further reduction of 3-15% from 1 July (BSW, 2011). However, even supposing that the FiT degression unexpectedly reverted to only 5%, and electricity prices rose by just 2% annually, that would only push back the crossover point to 2014. It will naturally occur earlier in regions of Germany with high insolation, and in other countries such as Italy.

6.7.3 What happens then?

Behrendt (2008) argues that demand will be determined by "subsidy programs" until grid parity is reached in the majority of markets, which will happen in a step by step manner, making it difficult to predict the size and rate of PV growth. Mints (2011) advises the industry to "Stop banging the grid parity gong", and instead focus on competitive pricing of solar electricity according to the characteristics of different markets, anticipating that incentives will become constrained and eventually disappear. Morris (2011) contends that feed-in tariffs will continue to be needed after grid parity, though does not explain how they would then operate.

No peer reviewed research on this topic was found, so it is hoped that the following thoughts will provide a small contribution to discussion. It is intended to develop them into a paper for submission to a peer reviewed journal.

Focusing on the domestic rooftop segment of PV growth in Germany, what is the significance of a feed-in tariff rate which is *below* the grid retail price of electricity? At first sight, there would appear then to be no point in choosing to receive the FiT, since all the electricity generated by the PV system would have to be fed into the grid, for a rate of payment less than the cost of importing from the grid the electricity consumed in the household. Depending on the interplay of PV system cost and FiT income in individual circumstances, owning a PV system might still constitute a microgeneration business which produced a positive return on investment. It seems improbable, however, that individual households would find that an attractive proposition, when they could receive a similar, even if slightly lower, return from a savings account without risk or paperwork.

Then again, it is argued in the present thesis that return on investment is not the sole motivation for having a PV system installed. Householders might be willing to have PV even if it means little or no return, or even incurring a small loss, for the sake of other benefits. As well as those relating to environmental concerns and social norms (e.g. "keeping up with the Müllers"), perceived benefits could include saving on buying in electricity from the grid by using in-house a proportion of PV system output, for the lifetime of the system, savings which would rise with increases in the grid retail price. The position is more complicated in Germany than in the UK (where in-house use is a bonus on top of the FiT), as the full FiT rate is payable only in the case of 100% export to the grid, and a lower rate if PV electricity is used in-house. However, the government has since 2009 sought to promote in-house use by setting the differential between full and lower FiT rates to less than the grid retail price, such that <lower FiT + avoided purchase from grid> is greater than <full FiT>.

The question nevertheless remains: does the arrival of grid parity limit the "shelf life" of the feed-in tariff mechanism? FiT could still be a worthwhile option even once its rate becomes lower than the cost of electricity from the grid: provided that the FiT rate at least covers the imputed cost of PV electricity, it still makes an individual rooftop PV system financeable. There may, however, be better approaches.

The life expectancy of a rooftop PV system, comfortably in excess of 20 years, means that its owner should expect to enjoy over that period increasing savings from in-house use of PV electricity, as the grid retail price continues to rise. Investing in a PV system means in effect "forward buying" for the next 20+ years the proportion of one's electricity consumption that the system can supply. That has a value which can be calculated from present and anticipated future grid retail prices, discounted to the extent that householders as opposed to professional investors think in such terms, rather than for example about simple payback time.

This could offer an interesting topic to investigate in relation to intertemporal decision making. Two principal issues are involved:

(a) the level of in-house use of electricity from a PV system

(b) the financeability of the system.

In-house use was to some extent discussed in 6.6 above. There is of course a trade-off between the cost of battery, flywheel or other electricity storage capacity, and the savings through avoided purchase of grid electricity. The 2011 feed-in tariff rates maintain the incentive to use PV electricity. Up to 30% in-house use receives a FiT of €¢12.36 per kWh, over 30% the rate rises to €¢16.74 (Solarportal, 2011). The rate for 100% export to the grid is €¢28.74, the grid retail price around €¢24; so the premium for in-house use is €¢7.6-12 per kWh.

To take as example one combination, for a house with average 3500 kWh annual consumption, a 4 kWp PV system, the 2010-11 "Solar League" average annual output of 921 kWh/kWp and achieving 40% in-house use of the PV electricity, the calculation at 2011 FiT rate and assuming a grid retail price of €¢24 per kWh is as follows.

PV system output = 4 kWp x 921 kWh = 3684 kWh

40% used in-house @ FiT rate of €¢16.74 = 0.4 x 3684 x 0.1674 = €246.68

60% exported to grid @ FiT rate €¢28.74 = 0.6 x 3684 x 0.2874 = €635.27

avoided cost of buying from grid @ €¢24 = 0.4 x 3684 x 0.24 = €353.76

Total benefit = <u>€1235.71</u>

cf. 100% exported to grid @ €¢28.74 = 3684 x 0.2874 = <u>€1058.78</u>

The additional benefit from a higher level of in-house use is just under €177 per year, which over the 20 year FiT lifetime amounts to €3540. Depending of course on storage capacity needed to achieve a given percentage of in-house use and the cost thereof, that would appear sufficient to cover the cost of storage.

Fast forward, however, to (say) 2013 and grid parity - and assume that there is no longer a feed-in tariff. Taking the grid retail price to be €¢26 per kWh, 40% of PV system output used in-house saves 0.4 x 3684 x 0.26 = €383 per year. Assuming a PV system cost then of €2000 per kWp so €8000 for 4 kWp, the raw return is €383/8000 = 4.8%. However, that omits the cost of storage capacity to achieve the 40% in-house use proportion. It also disregards the prospect of increasing savings through in-house use if the grid retail price increases. Clearly, the trade-offs and calculations become complicated.

The key question may well be that of financeability. How would a bank view a proposal to borrow the cost of a PV system plus electricity storage capacity to enable a high level of in-house use of the PV output? Would it be willing to lend, for instance, 75% of the cost even if the calculations indicated that the investment would recover its costs over 20 years? An important issue to investigate in this context could be whether a bank would prefer a guaranteed feed-in tariff, providing a continuing stream of income, over "virtual" income in the form of avoided cost of buying electricity from the grid. This requires assessment of the psychology, in relation to risk of loan repayment default. Do people tend to 'match' such avoided costs with loan repayment commitments and earmark them for that purpose, in the same way as actual income? Or do the avoided costs simply become savings which increase disposable income in the general household budget, which is liable to be spent rather than earmarked for loan repayments?

6.7.4 Net metering – the solution?

In terms of financeability, an attractive alternative to a PV system with battery or other electricity storage capacity could be "net metering", meaning that a household receives the same credit for electricity exported to the grid as it pays for electricity bought in from the grid. Some utilities already offer this, although not all at the same rate per kWh.

The advantage of net metering is that the grid provides the storage, accepting and distributing any electricity from a PV system which is surplus to household needs, typically in summer, and in effect time-shifting its availability to the household to a period when PV system output is below consumption, usually in winter. To put it another way, the household "banks" its surplus PV output in the national supply system, and cashes it in later when needed.

Provided that a kWh exported to the grid earns credit at the same rate as the tariff that the household pays for electricity from the grid, net metering is equivalent to a feed-in tariff at the grid retail price. Moreover, it is "index linked" in the sense that the value of the export credit rises to match any increase in the electricity price that the household pays. The value of a kWh of electricity from the PV system is then the same as the grid retail price. If that is greater than the imputed cost of a PV kWh, the investment should be worthwhile. Indeed it may be so, even if at installation the PV electricity cost is equal to or slightly above its value, viz. the grid retail price, since the latter may be expected to rise during the lifetime of the PV system. The total cost to the household of the combination of PV electricity and grid electricity to meet its consumption falls, compared with the scenario of buying 100% from the grid, or indeed that of receiving a fixed feed-in tariff and buying the balance of required electricity from the grid at an annually increasing price.

The same question as above arises, however, as to how a bank would view "virtual" income from a reduced electricity bill as a higher risk, in terms of loan repayment, as actual income from the feed-in tariff. The bank might regard the virtual income as equivalent to a salary increase, in its assessment of the household's credit rating. Or it might see it as increasing risk, and demand a higher rate of interest. As noted in Chapter 5.2, however, sensitivity analysis indicates that the interest rate has marginal effect on return on investment in a PV system. It would be interesting to conduct a small survey on this topic among banks involved in financing PV systems.

No indications have as yet been seen that the German government is considering net metering as alternative to the feed-in tariff. It is, however, a possible development to watch out for: that the present government, or its successor after the autumn 2013 federal election, will propose replacing the feed-in tariff mechanism with a legal requirement that electricity suppliers offer the option of net metering, giving credit for exported PV electricity at the same rate as the household pays for grid electricity. Such a proposal would be likely to include provisions to maintain incentives for in-house use, such as a limit on the proportion of PV output (perhaps 70%) to which net metering applied.

Chapter 7 : Conclusions

"In the long term, renewable energies will inevitably dominate the world's energy supply system. The reason is at the same time very simple and imperative: there is no alternative. Mankind cannot indefinitely continue to base its life on the consumption of finite energy resources."

European Renewable Energy Council (EREC, 2004)

7.1 Brief recapitulation

The research presented in this thesis investigated the question of whether solar photovoltaic capacity in Gèrmany will in the period up to 2020 continue to grow at a rate similar to that observed in recent years, meaning since 2004. In accordance with the title of the thesis, "An analysis of factors influencing the growth of photovoltaics in Germany, and the outlook to 2020", the research looked backwards to examine drivers of adoption of PV in Germany to date, and forwards to assess the outlook for capacity growth in the period up to 2020. Its principal focus was on the domestic segment of the market, i.e. small systems on roofs of individual dwellings. In particular, the research questioned the widespread, but it is argued rather simplistic, linkage of PV adoption to provision of "generous subsidies" through the feed-in tariff in effect 'bribing' people to install PV systems. The hypothesis was tested, as stated in 2.1 above, that: "Financial incentives, primarily the feed-in tariff, have catalysed the rapid build-up of PV in Germany, not so much by making it *profitable* as by making it *financeable.*".

The drivers analysed fall into the following two groups.

(a) cost-related, being the interplay of :

- government policy, put into practice through the Renewable Energy Sources Law including the feed-in tariff mechanism of support for PV installation ;

- the falling cost of PV systems, thanks to manufacturing technology and scale, and the affordability of systems ; and
- expectations in relation to return on investment in PV.

(b) socio-psychological factors :

- the environment consciousness of people in Germany ;
- intertemporal choice in purchase decisions ; and
- innovation diffusion theory.

They were investigated by means of a fieldwork survey of households in Germany, which obtained 400 responses; and of comparison tests and a sensitivity analysis of expected return on investment in a PV system, based on published data on over 1500 towns in the 'Solar League'. No similar research into motivation was found in the literature, which indicates that these investigations form an original contribution to knowledge in the field.

7.2 Findings

It is clear from the history that feed-in tariff (FiT) support has been a key factor in PV growth in Germany. The principal aim of the present research was to investigate *how* the FiT promotes installation of PV capacity, questioning the widespread perception that it is all about "generous subsidies" making PV a profitable investment.

The research found evidence that expectation of high return on investment is not the sole motivator of PV system installation, supporting the hypothesis that the FiT works, in many cases at least, by making PV *financeable* for people who want it for other reasons, rather than simply by making it lucratively *profitable* - as it were, "bribing" people to install PV.

That evidence consists of the following strands.

a. The fieldwork survey results include significantly higher ratings by households for financeability than for attractive return on investment, as reason to have a PV system installed. Other reasons besides return on investment also received similarly high importance ratings, including desire for independence from large electricity suppliers, and to help act against climate change. Concern about children's future appears to be a significant motivator.

b. Analysis of 'Solar League' data shows that in 2008-09 the return on investment to be expected from a rooftop PV system was broadly comparable to that from a risk free savings account, rather than a lucrative profit. Nonetheless many households installed PV.

c. Similar analysis for 2010-11 found markedly higher expected returns. However, examination of the market segmentation of PV capacity in Germany shows that growth in the household rooftop segment did not display a commensurate acceleration: it appears to be growing in line with a typical innovation diffusion S-curve. The sharp growth in PV capacity has occurred rather in the more "commercial" medium and large scale market segments, likely to be more concerned about exact level of return. Moreover, higher returns are available to householders through investment in a managed Solar Fund, without going through the process of PV system installation.

d. Data from successive surveys show the well developed environment consciousness of the Germans, high levels of support for solar energy, and antipathy towards nuclear power. Those offer a credible alternative motivation to that of profit for installing PV, supported by survey findings.

These findings support the hypothesis that financeability matters more to many individuals than does profitability as reason to install PV. The feed-in tariff mechanism has so far provided that financeability, making possible very low risk bank borrowing of the majority of a PV system's cost. This is consistent with the interpretation that the feed-in tariff has acted as the key enabler of conversion of desire for a PV system into actual installation, thus unleashing demand which existed for other reasons than profit-seeking.

Provided that the FiT mechanism continues to operate, demand in the domestic market segment may therefore be expected to sustain its progress along the diffusion curve (Fig. 28(b) on p.237 above). Even if PV system prices do not quite match further cuts in the FiT rate, the impact on projected return on investment would be minor. It is worth bearing in mind that lower returns in 2008-09 were enough to support demand (5.2.3 above); and that much capacity, across all market segments, has been installed where projected system output is relatively low (5.2.1 above).

The continuing fall in PV system price as adoption increases, through the experience curve effect, is no doubt a factor, as the price of an innovation usually is in its diffusion path. That does not necessarily mean that calculation of return on investment is the basis of decision, in particular by individual householders as opposed to professional investors. The decision may well also, or instead, depend upon the perceived scale of the financial commitment, simple payback time, intertemporal factors, cost per kWh of PV electricity in relation to grid retail price, and the prospect of at least a degree of independence in power supply. Overall the decline in price acts to maintain affordability and financeability, in relation to feed-in tariff income and ability to manage PV system financing.

7.3 Outlook : will the drivers continue to operate?

7.3.1 Environment consciousness

There is no indication of any change in the level of environment consciousness in Germany, nor in that of support for renewable energy including PV. The outcome of the series of Land elections in 2011, not least in Baden-Württemberg on 27 March, will offer a current barometer of voters' reactions to the government's energy policies and of the level of support for renewables.

7.3.2 Policy, including feed-in tariff

The political situation has become more complex than it was in mid 2009. At that point there was no sign that even if a right of centre government resulted from the federal election that autumn, it would jeopardise the evident benefits of PV growth: a new industrial sector creating tens of thousands of jobs and major exports, CO_2 emission reductions, enhanced energy security. Section 6.2.3 above examines developments since the CDU/CSU and FDP coalition took power.

The outlook as at the point of submission of this thesis is less clear-cut than in 2009. The feed-in tariff has been reduced by a total of 33% ; PV system prices have fallen by a similar percentage. The sensitivity analysis indicates that the FiT remains sufficient to cover PV system cost, and produce a return, higher than in 2008-09. PV growth has continued, indeed almost doubled from 3.8 GWp in 2009 to an estimated 7.2 GWp in 2010. There have, on the other hand, been calls for a cap on annual capacity growth. In addition, the extension of nuclear power plant operating lifetimes, if put into practice after the present safety review prompted by events in Japan, could threaten to displace renewably generated electricity, if there is any dilution of the latter's priority grid access. It is, however, possible that the electorate's reaction to the nuclear crisis at Fukushima may lead to a rethink on the advisability of reliance on nuclear energy.

Fell (2011b) urges the solar industry to engage strategically to influence energy policy, instead of focusing merely on the next quarter's results and leaving the nuclear power lobby to make the running on policy. He warns that EU energy commissioner Oettinger aims to rein back growth of renewables, by changing the EU target to "low carbon" energy sources, to include nuclear and CCS as of equal value. Photon (2011) predicts German government action to cap PV growth, leading to over-supply of solar modules, a price crash and for the first time in at least a decade a fall in the volume of annual new installations. It does not consider whether the drop in prices might be enough to bring PV to 'grid parity' sooner, making it an attractive proposition even without feed-in tariff incentives.

7.3.3 PV market growth and cost reduction

Pohl (2011) sets out the numerical implications of recent PV capacity growth in Germany, in relation to its national action plan for renewable energy as submitted to the EU (FRG, 2010). The action plan sets a goal of 52 GWp total installed PV capacity by 2020. Cumulative capacity to 2009 was 9.8 GWp ; adding the estimated growth in 2010 of 7.2 GWp makes 17 GWp. Supposing that growth in 2011 is in line with predictions at around 9 GWp, total capacity becomes 26 GWp - already halfway to the 2020 target. The remaining 26 GWp spread over the nine years 2012-2020 (inclusive) allows only 2.9 GWp annual growth.

Pohl argues that there is a potential impact on the global PV industry, as in the event of a steep drop in growth in Germany other markets could find it difficult to absorb the suddenly spare capacity, of 6-7 GWp. The global market could as a result stagnate, forcing down prices and hence FiT support rates, leading to successive company failures. That scenario requires, however, that other markets not grow sufficiently and soon enough to offset a reduction in Germany. The prospects appear good that such growth in other markets will occur. Indeed, it already is occurring in Italy and in the USA, which EPIA (2010a) forecasts will overtake Germany as world no.1 market in 2014 and where SolarWorld expect to make 75% of their sales within the next two years, as reported in Groom & Steitz (2011). It is also conceivable that Chinese producers would react to a shrinking of overseas markets by supplying more PV to their domestic market, increasing its size.

The PV industry has thus far proved itself able to reduce costs sufficiently to keep pace with FiT rate cuts. Predictions of company collapses and mergers have not been realised; investments in new production capacity continue to be made. The prospects for growth in a number of other markets seem good, which should help the industry to maintain its journey down the 'experience curve' of reducing cost. Scope still remains for improvements in production processes and module efficiency, contributing to reduction of PV electricity cost per kWh. Breakthroughs in PV technology are possible, such as new nanotechnology or organic polymer based cells, which if successfully transferred to the market would dramatically improve the economics of PV.

PV in Germany should reach 'grid parity' with the retail consumer price of electricity in 2013-14. Section 6.7 above considered the implications of that, which should be positive for PV growth.

7.4 The next few years: outlook sunny, or gloomy?

In Europe overall, the outlook is promising. As Liébard (2010) puts it: " The first European directives issued at the beginning of the 2000s set in motion what is now an unstoppable movement. Not only have the renewable sectors arrived, they have become the very cornerstones of national energy and economic policies.", not least because of their economic impact of €120bn turnover and over 900,000 jobs.

Globally, it is difficult to see the progress of PV being halted, though a brief slowdown in capacity growth is possible. The industry's growth, investment and scale make it a mainstream part of the energy sector. There is actual and potential growth in the USA, France, Italy, the UK, Ontario, Japan, China, India and many besides. The achievement in the short term of grid parity can be expected to boost demand further, aided by developments in grid management and electricity storage. Climate policy should be an important driver, if enough governments grasp that only renewables plus energy efficiency can deliver the CO_2 emission reductions needed in the time available.

Is it credible that Germany will choose to give up its hitherto leading role and turn away from the benefits of PV? The next two years will be the critical period, up to the next federal elections due in September 2013. The key issues relating to the 'policy' driver of PV growth are whether annual new capacity will be capped, and whether renewably generated electricity will retain guaranteed access to the grid. Loss of either would adversely impact growth prospects; although it is conceivable that a capacity cap would still leave room, perhaps as an explicit allocation, for adoption of household rooftop systems to continue at a similar rate.

A change of government, back to the SPD-Green coalition which laid the foundations for PV growth, would clearly be highly positive for its outlook. Even before the 2013 federal election, the outcome of Land elections may have a moderating influence on the Merkel government's energy policies, conducive to continued PV growth. They are, after all, politicians: a scenario of scaling down measures to restrict PV growth, and thus allowing it to continue at somewhere in the 3-7 GWp per year range, seems more likely than one of stubbornly pressing on with measures to hamper PV which could prove to be electoral suicide.

If the recent rate of growth does continue, PV's share of electricity output in Germany, 1.1% at the end of 2009 (BMU, 2010c), will increase rapidly. For instance, at 40% annual growth the total installed capacity doubles in 2 years; so by 2019, after five such doublings, it would reach 35% - hardly insignificant. As Table 29 in 6.2.1 above shows, the annual growth rate of PV since 2000 has never been less than 40% ; compound annual growth rate over that period was 71.6%. Even allowing for marked slowing of the growth rate, an average annual increase of 20% would double PV capacity in four years, reaching 9% of electricity supply in 2021. Even if other renewables did not grow at all from their 14.5% share in 2009 (BMWi, 2010b), total renewables would thanks to PV still reach 22.6% of 2021 supply - equal to the 2009 share of nuclear power.

Although he did not live to see it, the vision of Dr Hermann Scheer, co-architect of the Renewable Energy Sources Law and feed-in tariff, of a solar future for Germany and the world may yet be realised.

Chapter 8 : Suggestions for further research

8.1 Follow-up survey

It would be interesting to explore, by means of a further questionnaire based survey coupled with semi-structured interviews, the financial expectations of persons who have had PV installed, have decided to get PV, or are considering it. The central issue would be how important a factor, or condition, is the expected return on investment. Does simple payback time matter more to individuals, as opposed to professional investors? What level of expected return would be the minimum requirement for a decision to go ahead and have PV installed? The range of possibilities could for example be as follows.

- substantially higher than a 'high street' savings account, to compensate for the effort of arrange finance, installation etc ;
- somewhat higher than a savings account ;
- approximately the same as a savings account ;
- somewhat lower than a savings account would be acceptable, in view of environmental motivations or awareness of other benefits (e.g. 'bonus' electricity from PV system after the feed-in tariff period) ;
- not concerned about the level of return on investment, provided that the cost of a PV system would be recovered in an acceptable payback time, such as 10 years.

The length of payback time could be a further aspect to investigate. It constitutes an alternative way to view the relative costs and benefits of installing PV. Instead of projecting return over the 20 year FiT period on investment of own capital, a householder could think in terms of payback of the system cost (including financing) through FiT receipts over, say, 10-12 years; followed by 8-10 years of pure FiT income, and the bonus of 'free' PV electricity after the end of the FiT lifetime. That would of course defer the gain for a lengthy period, so could be an interesting study in terms of intertemporal decision making theory.

Another question of interest in that context is how people assess the possible purchase of a rooftop PV system, which involves substantial upfront cost - the majority of which may, however, be loan financed - with a complex mixture of continuing costs (loan capital and interest repayments, insurance, maintenance) and gains (FiT income, savings through in-house use of PV electricity), both early and spread over a long period. Do people view buying a PV system as more akin to (a) a "big ticket" purchase such as a car ; (b) a home improvement, e.g. a new fitted kitchen, which is not guaranteed to add to the house's eventual sale price; or (c) an investment, similar to one in a savings account or shares, in the expectation of a return? A survey plus interviews approach could elicit information relevant to the intertemporal issues referred to above.

8.2 Further data analysis

There remains considerable scope for further analysis of the fieldwork survey dataset - which will be deposited in the ESRC archive at the University of Essex.

One aspect as yet unexplored is the geographical dimension, for instance whether there is any significant variance in environmental attitudes or in reasons for wanting PV, as between eastern and western areas of Germany. The data include the 3 digit level postcode of each respondent, which does not identify house or street (5 digit level) but is sufficient to establish the location to within a few towns. For example, respondent no.1 - a CDU voter with 10 kWp PV system installed and maximum score for environmental responsibility - has postcode 646, which is for the area of Lindenfels and environs in Hessen. Conversion of postcode to place is available free of charge on www.postdirekt.de/plzserver/ .

Another unexplored aspect is whether persons in the 'elder' age group (55+) are more likely to adopt PV, because they have the time to obtain information, consider options, become involved in local initiatives, and have funds available to invest such as from a retirement lump sum on which investment in PV would provide a better return than typical savings accounts.

A further one is why a substantial proportion of survey respondents without children nonetheless gave a high rating for concern about the next generation.

The responses to the attitudinal statement "For my mobility I need a car with good performance" suggest that an interesting area of research, if not already investigated, could be the extent of dichotomy among Germans between a generally high level of environment consciousness on the one hand, and support for cars and motoring on the other.

8.3 Build on and further explore the Solar League dataset

Possibilities include the following.

(a) Plot the individual location of participating communities, and look for clusters. For example there seems to be one around Bayreuth, with lots of towns newly in the Liga in 2009-10 or 2010-11 season. Likewise in the western part of Rheinland-Pfalz, along the Luxembourg border region. They may be indirect evidence of local initiatives helping to boost adoption of PV, such as active Solar Lokal or RegioSolar branches.

(b) Add to the dataset demographic information on each community, e.g. via a premium subscription to the national statistics service Statista.de ; then analyse for possible correlations between PV capacity and e.g. voting, educational level, income band.

(c) Investigate the pattern of size of PV systems installed in the last two years, by mapping federal grid agency data - sorted by location - onto the set of Solar league towns. Has the fall in PV system prices led to installation of more new capacity in larger systems, thereby increasing overall capacity in League towns (from 750 MWp in 2008-09 to 2103 MWp in 2010-11) and the average capacity in Wp per resident? Has capacity in small, household rooftop, systems remained steady, or grown in line with a typical diffusion S-curve?

8.4 Do local initiatives lead to greater adoption of PV ?

As an expanded version of (a) in 8.3 above, it would be interesting to analyse whether PV adoption is significantly higher than average in towns where there is a local initiative to promote PV, and whether it includes prominent residents such as the mayor. This would include local branches of RegioSolar, Solar Lokal, the solar promotion association SFV, Eurosolar, and of course participation in the Solar League. This would also test Rogers' (2003) assessment of 'early adopters' as role models in their communities.

8.5 PV system financing issues

As suggested in 6.7.3 and 6.7.4, it could be helpful to conduct a small survey among banks involved in financing domestic PV systems, on whether they would in assessing the risk of providing a loan view "virtual" income from savings on the household electricity bill through in-house use of PV electricity, possibly assisted by a net metering provision, as equivalent to actual FiT income.

Another aspect of financing possibly worth investigating, discussed briefly in 6.7.3 above, is the extent to which individual households considering installation of a PV system take account of the various timing factors relating to cost and benefit. There is an interplay between the feed-in tariff rate prevailing at the time of installation, the length of the FiT payments period including any months remaining in the year of installation, and the current cost of a PV system.

8.6 Take-up of 'green electricity'

If a feed-in tariff constitutes a collective investment in building up capacity in renewably generated - meaning 'green' - electricity, why does anyone still sign up to a 'green electricity' tariff, especially if it involves paying a premium? This could be an interesting question to investigate. Candidates could include: people unable to have their own PV system, "deep Greens" who want to ensure that all their electricity consumption is matched by renewable generation, people in receipt of feed-in tariff income who want to contribute some of it back to help build renewables capacity further.

Such an investigation would probably need to involve a survey and interviews. A related question which could be addressed through meta-analysis of existing data is whether take-up of 'green electricity' tariffs is lower in countries where a feed-in tariff operates.

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ANNEX A

Fieldwork survey questionnaire (online) : statements + questions

-- with translations

Part 1 : attitude statements

A Der Klimawandel stellt eine echte und große Gefahr für die Menschheit dar.

Climate change is a real and great danger for mankind.

B Ich möchte kein zusätzliches Geld für erneuerbare Energien ausgeben.

I do not want to give out any additional money for renewable energy.

C Egal was wir tun, es macht keinen Unterschied, da z.B. China genug CO2 ausstößt.

It makes no difference what we do, since e.g. China emits plenty of CO2.

D Deutschland muss im Kampf gegen den Klimawandel eine führende Rolle spielen.

Germany must play a leading role in the fight against climate change.

E Umweltschutz ist Aufgabe der Regierung, nicht die des einzelnen Staatsbürgers.

Environmental protection is the task of government, not individual citizens.

F Für meine Mobilität benötige ich unbedingt ein leistungsfähiges Auto.

For my mobility, I need a car with good performance.

G Ich bin bereit auf lokaler Ebene meinen Beitrag zum Klimasschutz zu leisten, auch wenn es Geld kostet.

I am ready at local level to make my contribution to climate protection, even if it costs money.

H Ich mache mir Sorgen darüber, was für eine Welt wir unseren Kindern hinterlassen.

I am worried about what sort of world we are leaving to our children.

I Andere Probleme wie z.B. Lebenshaltungskosten sind mir wichtiger, als der Klimawandel.

Other problems, such as living costs, matter more to me than climate change.

J Wenn wir alle ein wenig zum Umweltschutz beitragen, erreichen wir bereits viel für die Umwelt

If we all do a little for environmental protection, we already achieve a lot for the environment.

[Scale: Agree fully --- Agree somewhat --- Neither --- Disagree --- Don't care/know]

Part 2 : reasons for wanting a PV system [scale: 1–10 , or "don't know"]

A Dank der Einspeisevergütung ist die Rendite wirklich attraktiv.
The feed-in tariff makes the return on investment really attractive.

B Ich möchte beim Kampf gegen den Klimawandel mit dazu beitragen.
I want to do my bit in the fight against climate change.

C Es ist wichtig mit modernen Technologien mitzugehen.
It is important to keep up with modern technology.

D Dank der Einspeisevergütung ist die Photovoltaikanlage finanzierbar.
The feed-in tariff makes a PV system financeable.

E Nachbarn bzw. Freunde haben bereits eine Photovoltaikanlage installiert.
Neighbours/friends have already installed a PV system.

F Aus Überzeugung, auch wenn die Rendite niedrig ist.
Out of conviction, even if the return on investment is low.

G Inspiriert durch eine lokale Initiative.
Inspired by a local initiative.

H Ich möchte dadurch unabhängiger werden.
I would like by this means to become more independent.

I , J [other - free to write in]

Part 2 : reasons for not installing a PV system [scale: 1–10 , "don't know"]

N Das Dach ist nicht geeignet.
Our/my roof is not suitable.

O Würde mich für eine Bürgersolaranlage entscheiden.
Am opting for a share in a collective community PV system.

P Nicht möglich, da mir als Mieter kein Dach zur Verfügung steht.
Not possible: am renting, and use of roof is not available to me.

Q Zu komplizierte und zeitintensive Antragsstellung (Bürokratie).
Too complicated to do - paperwork, bureaucracy.

R Möchte keinen großen/langfristigen Kredit aufnehmen.
Do not want to take on a loan of such size / for so long a time.

S Zu wenig Sonneneinstrahlung, nicht lohnenswert.

Too little sun on roof, would not pay off.

T Zu kompliziertes Thema.

All too complicated - don't understand about PV.

U Die finanziellen Mittel reichen dafür nicht aus.

Don't have sufficient financial means to do it.

V Ich warte auf sinkende Anlagenpreise.

Waiting for PV system price to fall.

W + X [other - free to write in]